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With which is incorporated The Institution of Aeronautical Engine

Edited for the Council by Capt. J. LAURENCE PRITCHARD, Hon. Fellow

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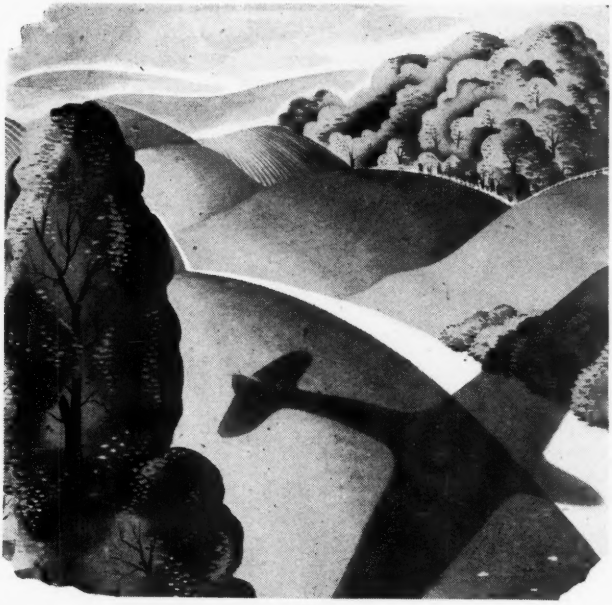

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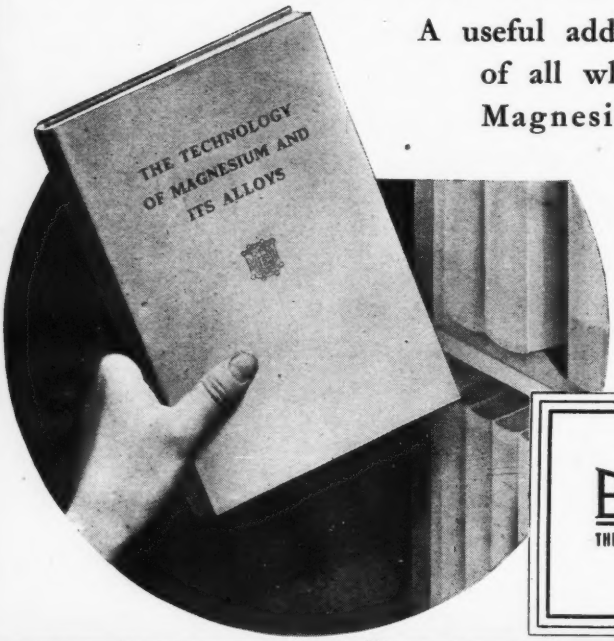

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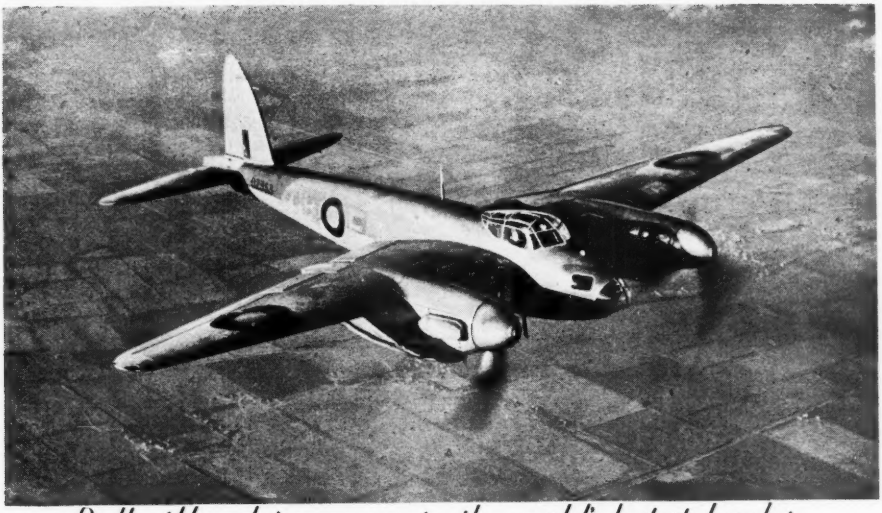

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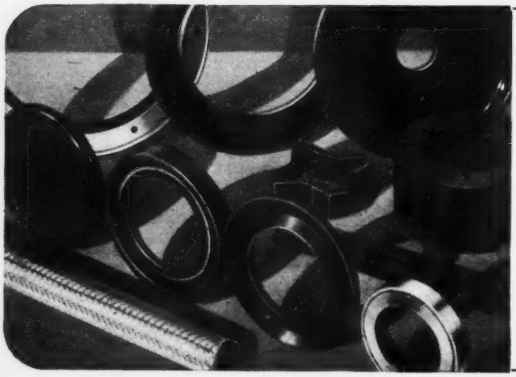

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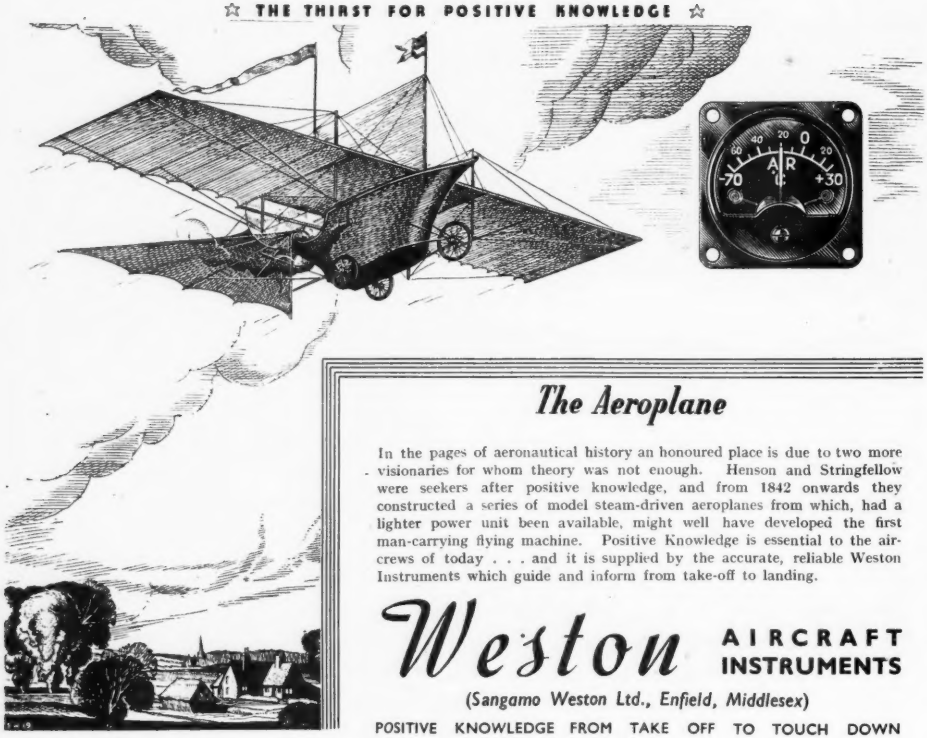

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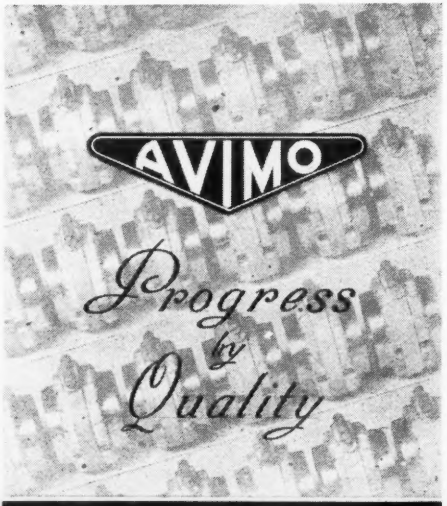

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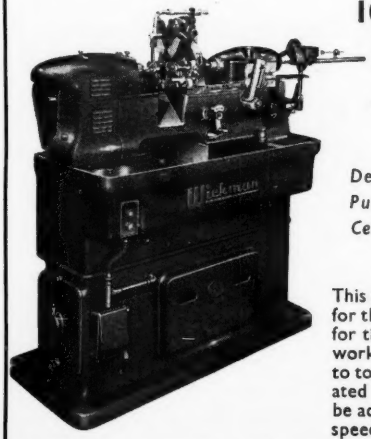

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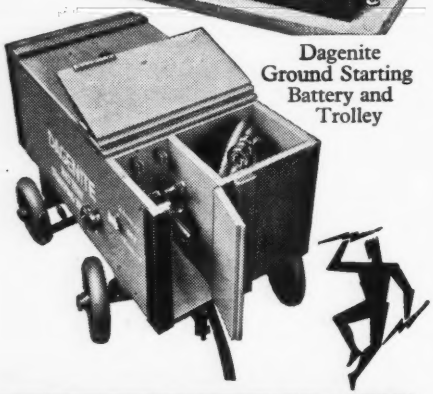

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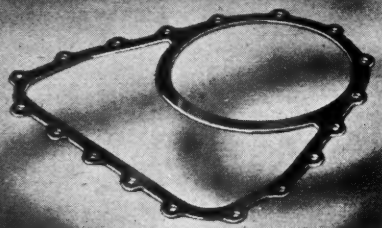

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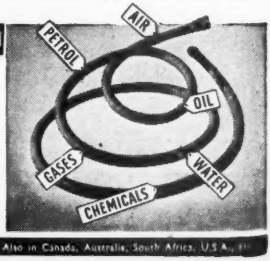

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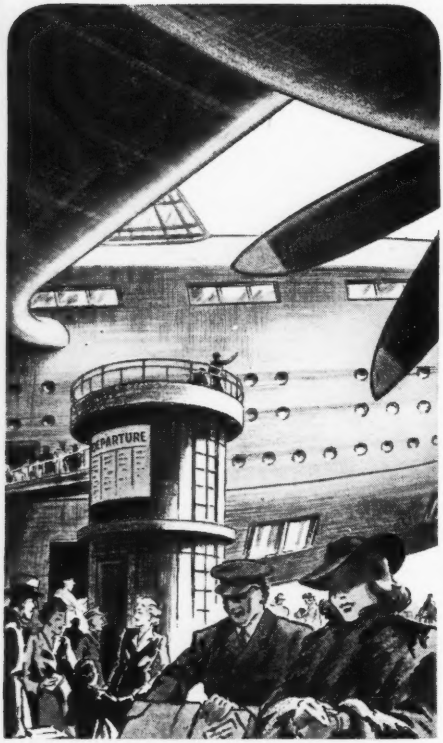

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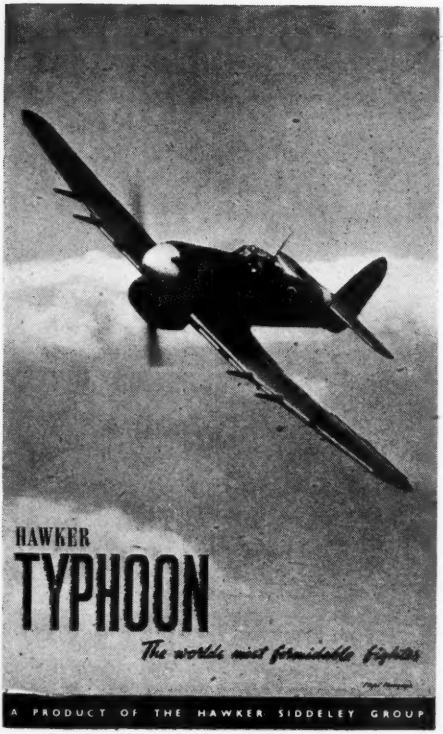

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THE JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY *was founded in* 1897 *in succession to the* ANNUAL REPORTS.

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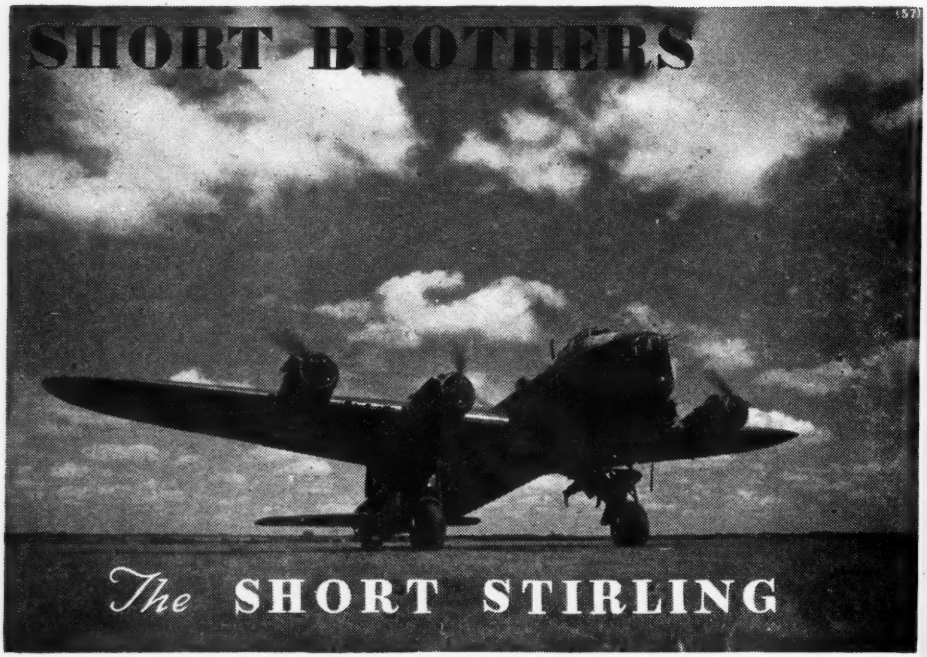

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MONTHLY NOTICES

JULY, 1943.

Education and Training of Aeronautical Engineers.

So much interest was shown at the meeting of June 25th, 1943, on the Education and Training of Aeronautical Engineers that it has been decided to have a further meeting. This meeting will be held in the Lecture Hall of the Institution of Mechanical Engineers (by kind permission of their Council), Storey's Gate, Westminster, S.W.1, on Friday, July 23rd, 1943, at 5.30 p.m.

A report of the discussion which has already taken place and written contributions will be available to those who wish to contribute to the second discussion. Supplies of these reprints are extremely limited, however, and cannot be made available to everyone.

Library Opening.

The Library will be open on Saturday afternoons from 2.30 p.m. to 5.30 p.m., until further notice. A member of the Graduates' and Students' Committee will be in attendance, and the Library will continue to be open as long as the attendance justifies it.

Graduates' and Students' Lectures.

The following lecture has been arranged as a Joint Meeting with the Graduates' Section of the Institution of Automobile Engineers, and will be held in the Library of the Royal Aeronautical Society, 4, Hamilton Place, at 7.30 p.m.:—

Wednesday, July 14th.—" Surface Finishing," by J. A. Oates, of " Aircraft Production."

Honorary Fellowship.

The Council have much pleasure in announcing that the Hon. E. P. Warner, Fellow, was elected an Honorary Fellow of the Society on May 27th, 1943.

Derby and District Branch.

Certain members of the Society have expressed a desire for a branch of the Society in the Derby and District Area. Will those members living in this area kindly write to Mr. F. Nixon, F.R.Ae.S., " Southlea," Hazelwood Road, Duffield, near Derby.

Reprinting of the Durand Volumes on Aerodynamic Theory.

Durand's " Aerodynamic Theory " is being reprinted in a form which duplicates as nearly as possible the original size and binding. A committee which is com-

posed of Dr. Theodore von Karman, Dr. Clark B. Millikan and Mr. E. W. Robischon, of the Aeronautics Department of the California Institute of Technology, has been organized to direct this non-profit venture. The cost is $30 per set. Arrangements can be made for anyone wanting a set to obtain them through the Society. Early application is advisable as only a limited number of sets will be available.

Associate Fellowship Examinations, May, 1943.

The following Candidates were successful in the May, 1943, Associate Fellowship (Section B) Examination:—

Akers, O. W. D.	...	Pure Mathematics.
Aynsley, T. W.	...	Aerodynamics.
		Strength of Aeronautical Materials.
		Pure Mathematics.
Baddeley, E. S.	...	Pure Mathematics.
Barnett, R. E. J.	...	Theory of Internal Combustion Engines.
Beard, C. A.	...	Theory of Machines.
Brotherhood, P.	...	Theory of Internal Combustion Engines.
		Aerodynamics.
Carthy, H. W.	...	Aircraft Materials.
Chaplow, R. G.	...	Theory of Internal Combustion Engines.
		Design (Aero Engines).
Chenery, J. F.	...	Strength of Aeronautical Materials.
Chivers, A. J.	...	Aerodynamics.
Coker, O.	...	Theory of Internal Combustion Engines.
		Aircraft Materials.
		Design (Aero Engines).
Conea, M. M.	...	Aircraft Materials (First Place).
Connolly, T. G.	...	Aerodynamics.
		Pure Mathematics.
Cowan, P. K.	...	Strength of Aeronautical Materials.
Eagle, J. W.	...	Aircraft Materials.
Ellins, M.	...	Pure Mathematics.
		Strength of Aeronautical Materials.
Elliott, J. S.	...	Pure Mathematics.
		Design (Aircraft).
		Strength of Aeronautical Materials.
Evans, J. D.	...	Design (Aircraft).
Eyers, J. A.	...	Pure Mathematics.
		Theory of Machines (First Place).
		Theory of Internal Combustion Engines.
Fail, R. A.	...	Pure Mathematics.
		Aerodynamics.
		Strength of Aeronautical Materials.
Fletcher, G. L.	...	Pure Mathematics.
		Aerodynamics.
Golding, G. H.	...	Pure Mathematics.
		Design (Aircraft).
Grant, D. G. S.	...	Theory of Machines.
Haines, J. E.	...	Pure Mathematics.
		Strength of Aeronautical Materials.
		Theory of Internal Combustion Engines.
Harris, J. D.	...	Pure Mathematics (First Place).
		Aerodynamics.
		Strength of Aeronautical Materials.
Harris, H. W.	...	Pure Mathematics.
		Theory of Internal Combustion Engines.

Hartwell, M. R. G. ...	Applied Mathematics.
Harwood, F. J. W. ...	Design (Aircraft).
	Strength of Aeronautical Materials.
Harwood, J. H.	Strength of Aeronautical Materials.
	Aerodynamics.
	Pure Mathematics.
Hidson, E. J.	Pure Mathematics.
	Design (Aircraft).
Holmes, J. D.	Pure Mathematics.
	Design (Aero Engines).
Hughes, J.	Pure Mathematics.
	Design (Aircraft).
Hyde, R. G.	Pure Mathematics.
	Aerodynamics.
Jermyn, D. A.	Pure Mathematics.
Knowles, A. N.	Applied Mathematics.
	Strength of Aeronautical Materials.
Labett, C. W.	Design (Aircraft).
Leavy, L. E.	Applied Mathematics.
	Aerodynamics.
	Design (Aircraft).
Lewin, I. H.	Pure Mathematics.
	Strength of Aeronautical Materials.
	Design (Aircraft).
Lipman, S.	Applied Mathematics.
	Design (Aero Engines).
Lloyd, R. M.	Strength of Aeronautical Materials.
McCulloch, J.	Pure Mathematics.
Naismith, S. T.	Applied Mathematics.
Obee, K. R.	Pure Mathematics.
	Design (Aircraft).
Parkinson, J.	Theory of Machines.
	Theory of Internal Combustion Engines.
Peterson, P.	Design (Aero Engines).
Pike, Miss E. C. ...	Aerodynamics (First Place).
	Design (Aircraft) (First Place).
Poole, G. D.	Pure Mathematics.
	Strength of Aeronautical Materials (First Place).
	Design (Aircraft).
Pringle, B.	Applied Mathematics (First Place).
Radford, J.	Pure Mathematics.
Roberts, D. L.	Pure Mathematics.
	Theory of Machines.
Robertson, I. W. C. ...	Pure Mathematics.
Rowan, P.	Pure Mathematics.
	Design (Aero Engines) (First Place).
	Theory of Internal Combustion Engines (First Place).
Saunders, P. E.	Applied Mathematics.
Sheath, P.	Pure Mathematics.
	Aerodynamics.
Smith, J.	Design (Aircraft).
Tavener, R. I. B. ...	Applied Mathematics.
	Design (Aero Engines).
Thirkettle, J. R. ...	Aerodynamics.
Tooley, C. P. D. ...	Pure Mathematics.
Toulson, K. W.	Pure Mathematics.

Walker, D.	Pure Mathematics. Aerodynamics. Theory of Internal Combustion Engines.
Walters, H. J.	Theory of Machines. Aircraft Materials.
Ward, T. H.	Applied Mathematics.
Wels, T. A.	Aerodynamics.
Wilcocks, D. A. ..	Aircraft Materials.
Williams, R. D.	Pure Mathematics. Strength of Aeronautical Materials.
Willis, V.	Pure Mathematics. Design (Aero Engines). Theory of Machines.
Woor, D. F.	Aircraft Materials.

Baden-Powell Memorial Prize.

Mr. J. D. Harris was considered by the Examiners to be the best Candidate in the May, 1943 entries and has been awarded the Baden-Powell Memorial Prize.

Election of Members.

The following members have recently been elected:—

Honorary Fellow.—Edward Pearson Warner.

Associate Fellows.—Leonard Charles Alfred Coombs (from Student), Simon Crann, Alfred Charles Crockford, Henry William Dunn (from Associate), James Henry Harrop, Wilfred George Hicks, James Macaulay-Service, Cyril Thomas Sculthorpe, Frederick Nicholas Slingsby (from Associate), Maurice Sydney Spickernell (from Graduate), Leslie George Whitehead (from Student).

Associates.—Henry Haydn Atterbury, Herbert James Bayliss, David Barclay Ross Briant (from Companion), Percy George Chaplin, Eric Cookson, Robert William Corkling, William Crowne, Robert Davenport, Vincent Bertram Freeman, James William Haggas, Robert Milroy Hayes (from Companion), Douglas Francis Henderson, Gordon Willoughby Howland, John Maynard, James Patrick McCormick, Percival George Preston, Thomas Norman Leofric Pughe, Charles Walter Sizer, Harold Short, Peter James Smith, William Sidney Francis Smith, Frank George Tearle, Albert Gainsford Towndrow, Louis Charles Jones Warren, Douglas Warner Williams, Joseph Edward Williamson, Leonard Donald Wilson, Richard Hector Wynne.

Graduates.—George Murison Addison, Albert Broadbent, Gordon Drummond Frier (from Student), William Henry Noel Gibby, Alan Baird Hunter, Dennis Hill (from Student), Alan Windle Lee, Leslie Raymond Nash, William Lander McAllister (from Student), David Rendel, Deryck Charles Smith, Evers Turner Buchanan Smith, Bernard Hugh Stanley (from Student), Peter Sweetman, Peter Sumner Wilson.

Companions.—John Herbert Condy, Reginald Victor Longinotto, Harold James Lowings.

Students.—Robert Ernest Agar, David Geoffrey Ainley, Frederick Brian Butler, Robert James Dixon, Andrew Fyfe Duncan, William Little Farish, Derek James Hardy, Anthony Herbert-Caesari, Harold Edward Holmes, Thomas Frederick Holmes, William Sowden Jones, Ian Martin Farquharson Keith, Richard Charles Rogers, John Syrad, Roy Albert Tier, John Michael Townsend.

Additions to the Library.

Pamphlets in italics, with location reference following in brackets.
Books marked * or ** may not be taken out on loan.

BB.b.104.—Introduction to Aircraft Design. Thomas P. Faulconer. McGraw Hill. 1942. 19/-.

*D.b.184.—*First Report of an Independent Committee on the Future of Civil Aviation. Capt. A. G. Lamplugh (Chairman). Privately Printed.* 1943. (PD.2.b.)

*D.b.185-188.—*Parliamentary Debates, House of Commons Official Report: Vol. 388, No. 48 (31/3/43), No. 50 (6/4/43); Vol. 390, No. 72 (1/6/43); House of Lords, Vol. 127, No. 50 (13/4/43).* (Civil Aviation Debates.) *H.M.S.O.* 1943. *6d. each.* (Y.20.ii.)

E.d.17.—Aircraft Detail Drafting. Norman Meadowcroft. McGraw Hill. 1942. 15/6.

E.f.99.—Testing of Aero Engines. R. A. Beaumont. Sir Isaac Pitman. 1943. 7/6.

E.f.100.—Airplane Construction and Repair. John E. Younger. McGraw Hill. 1931. 21/-.

EE.c.71.—*Exhaust Pipe Phenomena. (Lecture before the Manchester Association of Engineers, November 21st,* 1942.) *G. F. Mucklow. Manchester Association of Engineers.* 1943. (PEE.2/10.)

*G.b.3.—*British Standards Institution, Specifications.* 1943. (1/- *each*):—
4F.15. Hemp Lines and Ropes for Kite Balloons.
4F.32. Hemp Cordage.

G.d.16.—Process Practices in the Aircraft Industry. Frank D. Klein, Jr. McGraw Hill. 1942. 19/-.

G.e.A.87.—*Heat Treatment of the Wrought Aluminium Alloys. Part II. Equipment. (Bulletin No. 4.) Wrought Light Alloys Development Association.* 1943. (PG.3.a.17.)

J.g.194.—*Smithsonian Miscellaneous Collection, Vol. 103, No. 10. (Publication 3,729.) A Remarkable Reversal in the Distribution of Storm Frequency in the United States in Double Hale Solar Cycles, of interest in Long Range Forecasting. C. J. Kullmer. Smithsonian Institution, Washington.* 1943. (Y.30.i.)

L.a.45.—*Aerobatics Simply Explained. Wing-Com. R. Cravell. Sir Isaac Pitman.* 1943. *9d.* (PL.1.a.6.)

L.d.91.—Aircraft Navigation. Part I, Theory. H. Stewart and A. Nichols; Part II, Practice. S. Walling and J. C. Hill. (Both parts in same volume.) Cambridge University Press. 1943. 5/-.

L.d.92.—Elementary Air Navigation. R. K. Vanderford. Gale and Polden. 1943. 3/6.

L.j.88.—Aero-Photography and Aero-Surveying. James W. Bagley. McGraw Hill. 1941. 24/6.

Q.c.40.—Loughborough College Calendar, 1943-44. Echo Press, Loughborough. 1943.

R.c.272.—The Aeroplane: Past, Present and Future. C. Grahame White and H. Harper. Werner Laurie. 1911.

RR.117.—The Way to Fly." "Avion." C. Arthur Pearson. 1919.

S.e.64.—Combined Operations, 1940-1942. Ministry of Information. H.M.S.O. 1943. 1/-.

S.e.65, 66.—*Future Controls Over German Aviation. Edward P. Warner. Reprint from "Foreign Affairs" (U.S.A.), April*, 1943. (*Two copies.*) (Y.17.c.G.)

TT.a.44.—The Flying Squad. Col. W. A. Bishop and Major R. Stuart Wortley. Harrap. 1931. (Fiction.)

TT.a.45.—Contact. Elliott White Springs. John Hamilton. (Undated.) (Fiction—1914-18 war period.)

*V.1/23.—A.S.M.E. Transactions, Vol. 64, 1942. American Society of Mechanical Engineers. 1943.

*V.5/48.—Institution of Mechanical Engineers: Proceedings, Vol. 148 (July-Dec., 1942). Institution of Mechanical Engineers. 1943.

J. LAURENCE PRITCHARD, *Secretary and Editor.*

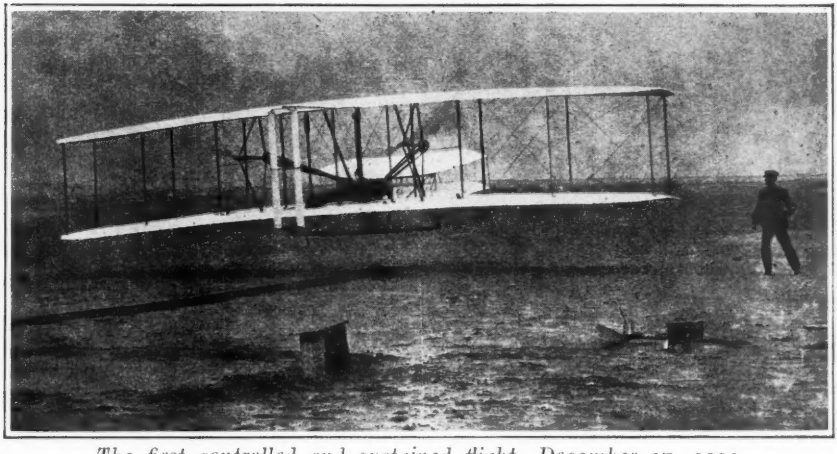
POST-WAR TRANSPORT AIRCRAFT

By Dr. Edward P. Warner,

Vice-Chairman, Civil Aeronautics Board, Honorary Fellow of the Society.

THE THIRTY-FIRST WILBUR WRIGHT MEMORIAL LECTURE,

The Thirty-first Wilbur Wright Memorial Lecture was delivered before the Society on Thursday, May 27th, 1943, at 6.30 p.m., in the Lecture Hall of the Institution of Mechanical Engineers, Storey's Gate, London, S.W.1, by permission of the Council of the Institution. The chair was taken by Mr. A. Gouge, F.R.Ae.S., President of the Society.



The first controlled and sustained flight, December 17, 1903, Orville Wright piloting the machine; Wilbur Wright on foot.

The President: The occasion was the 31st Wilbur Wright Memorial Lecture. This lecture ranked as the most important aeronautical event of the year, and perhaps the most important aeronautical event in the world. The Council of the Royal Aeronautical Society could pay no higher compliment to a man than to ask him to deliver this lecture. As most of the audience already knew, it is customary for this lecture to be read in alternate years by an American and by an Englishman. This year it is the turn of the United States to provide the lecturer, and no one more suitable than Dr. Warner could have been chosen to add to the list of the famous men who have given this lecture in the past. Dr. Warner was one of those many distinguished Americans who acted as unofficial ambassadors to this country and do so much to promote co-operation between the United States and Great Britain. His career had been a very distinguished one; he was experimenting with models and gliders as long ago as 1900. During the last war he undertook specialised research work for the U.S. Army. Of

recent years he had been a member of the Committee for Civil Aeronautics in the U.S.A. In addition to publishing numerous well-known technical reports he had left his mark on all branches of the technical side of aviation. For some time he was Assistant Secretary for Aeronautics to the U.S. Navy, while for a number of years he was Professor of Aeronautics at the Massachusetts Institute of Technology. He had also written a standard work on Aeroplane Design, which has been adopted in most of the United States Universities. In 1920 he became an Associate Fellow of the Royal Aeronautical Society, in 1928 a Fellow, and in 1943—two hours previously—he was elected by the Council as an Honorary Fellow. Only 18 such Honorary Fellows have been elected in the last 76 years. (The announcement of the award of Honorary Fellowship to Dr. Warner was received with long applause.)

Dr. E. P. WARNER: In accepting the Diploma of Ronorary Fellowship, he knew there was no greater honour in the field of Aeronautics, and none that he would value more highly. He valued it especially as a mark of that generous friendship which he had found in England ever since he first visited that country twenty-six years ago. (Dr. Warner then proceeded to deliver his lecture.)

POST-WAR TRANSPORT AIRCRAFT.

By Dr. EDWARD P. WARNER,

Vice-Chairman, Civil Aeronautics Board, Honorary Fellow of the Society.

I have been deeply appreciative of the action of the Council in inviting me to deliver this lecture. No one could be otherwise. The Wilbur Wright Lectureship has been illustrious in the qualifications of the thirty speakers who have been my predecessors on this platform; but it is illustrious also in itself, in the manner of its founding, and in the manner in which the Royal Aeronautical Society has carried it on in an unbroken series through two wars and the years between.

In this annual homage to the memory of Wilbur Wright you have provided a reminder of the swift and generous appreciation that the Wright Brothers' work always found in England. It reminds us, too, in a field that has too often been the subject of national self-glorification and in a time when chauvinism has been rife, that aeronautical science, like other sciences, knows no barriers of race or nation. The Wrights, like the noblest of their successors in Britain and elsewhere, sought knowledge for its own sake and that it might benefit all mankind. We are well on our way to the time when we can again think of aeronautical science in terms of pure benefit and of new-found knowledge freely broadcast to the world. Those who have perverted the aeronautical labours of a generation into the service of evil are suffering daily and nightly retribution by the instrument of their own choosing.

While the process of retribution goes forward, with the United Nations united in dealing ever heavier and more frequent blows, and with every effort properly bent on bringing the assault to a successful conclusion, it seems an anachronism to talk of the conditions under which aircraft will be employed in the post-war world. I have hesitated over the subject; but I have found courage to undertake it in a conviction of the appropriateness of the theme to the spirit and the purposes of Wilbur and Orville Wright, and also in a precedent. I found the precedent in the Twenty-eighth Wilbur Wright Lecture. It was delivered, as you all recall, by Dr. Roxbee Cox. His subject was "The Future of British Civil Aviation," and the date was May 30, 1940. It came at the end of a month in which every newspaper and every radio news bulletin brought fresh news of tragedy and disintegration to which there seemed to be no end. It came in the very week of the miracle of Dunkirk; but one would have suspected little of the

tragedies and anxieties of the time from the *Journal's* report of the calm and ordered procession of events upon that occasion, and of Dr. Cox's review of the responsibilities and of the opportunities that lay far ahead. The Chairman, Lord Brabazon of Tara, spoke then of your determination to continue the Society's lectures, "even if it became necessary to hold them, like the early Christians, underground in catacombs." The storm raged fiercely; but for many months now you have been out of the catacombs, and Hermann Goering and his cohorts are moving in.

Transport aircraft wear battle dress now. They are carrying cargoes, and being called upon for services, and being judged by standards that are alien to anything in their past, and we may hope equally alien to their future. With the end of the war they will return to the missions of commerce. The builders of aircraft now fix their attention upon the development of new military types; but during the period that extends from the end of the second year after the war to the end of the fourth, a considerable number of new models of transport aircraft are going to reach the market. It is of that first post-war generation of aircraft that I want especially to speak to-night, and of the conditions under which they will operate.

In connection with such a study, even though it be focussed upon a relatively brief period, one must make many assumptions. The first and most fundamental concerns the central purpose for which air transportation is to exist. If the primary aim is to be the rendering of a genuine public service to the largest possible number of people, freeing their personal movements and their communications, and the movements of the products of their manufactures and arts and tillage, and bringing into the stream of commence the products of regions now inaccessible, and enriching the lives of the people of those regions in return, the development will follow a certain course, and certain types of aircraft will be sought. If on the other hand air transport is to be judged primarily in terms of its contribution to national prestige, and used as a pawn in a political game, we shall have another type of service, and a demand for aircraft to a different specification, in which showiness will play a larger part than serviceability. In purely physical terms, air transportation is making the world one neighbourhood. If there is so little wisdom among us at the end of this war that we lose the opportunity to make the world a neighbourhood in fact, the handicapping and perversion of the development of air transport will be a part of the price that we shall pay.

Among the alternatives I choose the first, the alternative of public service, as an expression not only of preference but of well-founded hope. I shall proceed accordingly.

I am concerned here with economics and with engineering; and I shall say nothing of politics except to make a personal profession of faith, in which I hope you can all join. My hopes for the future are rooted in the central hope that air navigation agreements will henceforth be drawn to the presumption that air transportation is a good thing; that the need of the whole world to share in its benefits should be a prime consideration in the planning of air routes; and that there shall be no return to those evil days when air transport was regarded with such caution and suspicion that it had to be administered in paltry and carefully measured doses, with the authorization to operate internationally being parsimoniously doled out, schedule by schedule.

If air transportation is to be judged as an instrument of commerce, the extent of the service that it can render will be determined by a balance between the special value of the service and the cost of supplying it. The particular type of service that will exist will be determined in part by the cost and in part by the preferences of the consumer. The analysis of the preferences of travellers and of the conditions which determine the flow of commerce become a part of aeronautical science.

As is the way of customers, travellers by air have a set of incompatible desires. They seek the utmost in speed, and the utmost in economy. They seek a high degree of regularity and frequency of service, and exact adherence to schedule, together with perfect safety. They welcome—if they do not absolutely demand —the introduction of more and more luxurious and spacious accommodations.

The realization of their desires will be subject to economic controls. If the type of service that would yield most satisfaction appears to be unduly costly, we shall have to accept a substitute. All that I say on preferences must therefore be taken with reservations on the necessity of exploring its economic practicability before it can become the basis of action.

The effect of the performance and characteristics of the aircraft upon economy can be analyzed mathematically. I shall discuss the results of such an analysis; but before reaching that point certain factors, and most particularly the factor of aeroplane size, may be discussed in terms of passenger preference and practical operating problems.

There is a common disposition to think of the future of air transportation almost exclusively in terms of aircraft of giant dimensions. I shall have something to say of the virtues of size; but I want also to present the case, too often ignored, for the opposite extreme. There is little doubt that most travellers, if given a free choice upon that point alone, would prefer a 100-passenger aircraft to one of a quarter that size. Spaciousness is impressive. It is not so clear, however, that the typical traveller will be ready to abide by the full consequences of such a decision.

The consequences appear in the sacrifice of the flexibility and frequency of service which air transport is able to offer as one of its distinguishing characteristics. We do not always recognise that quality at its full value. Only the highway motor shares with the heavier-than-air craft the ability to combine a very high degree of efficiency and performance with small size.

Air transport and its patrons have already owed much to the relatively high efficiency and economy obtainable with aircraft far smaller in carrying capacity than the smallest unit that could be a serious contender for commercial patronage on the rails or on the sea. Their favourable position may be illustrated by a specific example. The total number of passengers moving over the railway line between Boston and New York, 184 miles apart by airline distance, in 1933 (the only year for which complete and specific records exist on point-to-point travel on American railways) averaged approximately 2,500 per day. In 1940 the general volume of passenger travel on American railways was approximately 67 per cent. higher than in 1933, and the average flow over the Boston-New York line had therefore presumably increased to about 4,200 per day. In September, 1940, in which month a very complete survey and analysis of the traffic on the airlines of the United States was made, the average daily flow by air along the Boston-New York sector was 672 passengers. The average number of travellers each day by air was only about 16 per cent. of the average by rail, yet the number of schedules between the two cities by air substantially equalled the number offered by the railways—22 trips in each direction as against 23. At the same time the number of daily schedules in each direction between New York and Chicago, 720 miles apart by airline, were 39 by air and only 24 by train.

Perhaps this is a good point at which to express my regret that I have had to limit myself in the instances just cited, as I shall have to in many others, to American examples and experience. Although the specific conditions of airline operation in the United States are in many respects different from those in Britain and on Britain's overseas connections, I believe that the general conclusions derived from American experience will remain largely valid elsewhere. In any case I have not had at my disposal any studies of the distribution of traffic or the costs of operation for the airlines of any part of the British Commonwealth that are as complete as the available records of the American services.

Whatever preferences the travelling public may have for large aircraft, it is beyond doubt that they have a strong preference for high frequency of departure, especially on short trips. A voyager from London to Calcutta may be expected to make his plans far enough ahead of time so that the necessity of arranging them to fit a departure scheduled for a particular hour will be no major inconvenience; but the traveller between London and Manchester by air would presumably prefer something like omnibus frequency, so that he might leave his office at any moment with confident anticipation of finding an aeroplane departing for Manchester within a few minutes after his arrival at London's airport.

The flexibility that the use of small aircraft allows has another advantage inherent in the nature of air transportation. It increases the number of passengers who can be provided with service directly from origin to destination. Since aircraft will always be affected by the wind, and the wind is a highly variable factor, airline schedules are likely to continue substantially more fallible than those of surface transportation. Uncertainty of schedule makes uncertainty of connections. Although improvements in traffic control methods and in radio aids to navigation after the war ought to allow a substantial improvement upon the past record, it will remain more difficult to make close connections by air than by rail, where the passenger may step across the platform from one train to another carrying his baggage in his hand. That is one of the points that has disturbed me about the plan recommended six years ago by Sir Henry Maybury's committee, centred as it was upon the pivotal position of a junction airport and presumably calling for a large number of changes of aircraft.

More important than the uncertainty of connections, however, is the loss of time entailed in every intermediate stop. The interpolation of a stop in the middle of a long straight run on an American railway increases the total time between terminals by an average of three minutes, including the time lost in braking and in accelerating and the time actually at rest. The corresponding figure for an aeroplane averages about 15 minutes in American experience, even for stops where there is no refueling. It is never less than 10 minutes, and tends to become longer as either the size of the aircraft or the volume of airport traffic increases. The loss of time by each stop may be lengthened, too, by the increasing complication of traffic controls which an increasingly intensive use of the air-space may demand. The time by air between New York and Boston or New York and Washington (each of these routes being approximately a 200-mile flight) is nearly 20 per cent. longer on the schedules which make an intermediate stop than on those which proceed without stop between terminals; and the experienced travellers seek out the non-stop flights.

"Non-stop from everywhere to everywhere at 10-minute intervals," is the patron's ideal. It is scarcely realisable, but it comes nearer to being realized with a small aeroplane than a large one. If an average of 20 passengers want to leave London for Edinburgh by air between 5 and 6 o'clock each afternoon, with another 20 for Sheffield and Leeds and Newcastle, and if aeroplanes of 25-passenger capacity are being used, there will be justification for a non-stop schedule to Edinburgh and another to make the intermediate stops and care for the local traffic. If on the other hand we are committed to 60-passenger aeroplanes it will be necessary to run a single schedule and let that one make all the stops, at the expense of a considerable loss of time for the Edinburgh passengers, in order that a reasonable proportion of the available seats may be filled.

High frequency and the maintenance of many non-stop point-to-point connections face one practical handicap in the limited capacity of ground facilities. Under pre-war conditions, an airport with a double system of runways and with a well-established traffic pattern might have been able to handle one transport landing every minute during the day and night in clear weather, with take-offs with a similar spacing. In minimum visibility conditions, on the other hand, a minimum spacing of 15 minutes between arrivals was maintained until about two years

ago. That interval has now been reduced to a minimum of five minutes at those American fields having approach control, which makes all pilots subject to the direction of the airport control tower operator from the time when they pass a marker about 15 miles distant from the field; but even with properly designed runways and approach control the best that can be hoped for in minimum ceiling and visibility conditions would be the handling of some 30 arrivals and departure per hour.

At the peak of activity, before the withdrawal of transport aircraft from the American routes to put them into military service had reduced airline operations, New York's municipal airport had a total of 244 scheduled landings and take-offs each day.[1] Of that number, only nine landings and seven take-offs, or 7 per cent. of the total movements, were scheduled between midnight and 6 a.m.; whereas 55 landings and 45 take-offs, or 41 per cent. of the 24-hour total, occurred between 4 and 10 p.m. Fourteen take-offs were scheduled in one hour; 12 landings in another.

One cannot discuss in detail the means by which wartime developments may reduce the degree of separation that must be maintained between aircraft in the overcast to avoid the risk of collision; but it is possible to say with some confidence that post-war radio will be scarcely a recognizable relation of its pre-war predecessor. The experience gained in dispatching and co-ordinating the movements of anything up to 1,000 bombers in a night, too, will make itself felt in the technique of transport operations after the war. I think it is reasonable to hope that the capacity of a well-planned and well-operated airport may be increased to 40 landings and 60 take-offs during the busiest hour of the day, or four times the total attained in 1941 at New York, and that that number of operations would be kept close to schedule, landing and taking-off at their designated intervals, even in low visibility. Some of my friends with special qualifications in this field consider even that estimate too conservative, and I believe that with a sufficient number of parallel sets of runways the movements of aircraft in the airspace can be so co-ordinated as to allow 150 operations per hour in bad weather, even under instrument conditions. If more flights are required to satisfy the demand of traffic for frequency and flexibility than a single airport can handle, duplication of airports will be necessary. The number of schedules that will actually be needed by any particular city will depend upon the total amount of traffic that is likely to exist between that city and each of a multitude of others, and upon the size of the smallest aircraft that can be operated with reasonable economy. Obviously if it were possible to secure a proper degree of safety, comfort, and economy of operation in a four-passenger aeroplane, the number of routes radiating from a single point that could be kept in useful and profitable operation would be vastly greater than if the smallest feasible unit were in the 20-passenger range or larger; but obviously the sub-divisibility of the units of air transportation reaches a limit somewhere.

As a necessary preliminary to the examination of the characteristics of transport aircraft, therefore, I turn to the consideration of post-war air traffic volume.

I must again express regret at being so exclusively dependent upon American data; but what will be true of New York will presumably be true in many respects of London also.

In estimating future traffic, one may draw upon present records of air travel and upon the existing volume of surface travel. The most complete and most recent of American traffic surveys indicates that in 1940 the movement by air between major cities in the United States over a distance of 1,000 miles or more typically ranged around 20 per cent. of the total travel between the same points by rail and air together. The ratio of air travel to surface travel decreases with decrease of distance, but for distances as short as 200 miles it was still around

[1] "Capacity and Operating Problems" by A. F. Bonnalie, of United Air Lines; Chicago Airport Conference, October 31, 1941.

11 per cent. The figures in the tabulation of specific cases that I have reproduced here include no transient traffic. They relate only to travellers whose journey originated in one of the cities named and terminated in the other.

Routes	Airline Distance (Miles)	No. of Inter-City Railroad Passengers in 1933	Same, Corrected for increase in travel from 1933-40	Inter-City Air Passengers, Sept., 1940	Estimated Total of 1940 Inter-City Air Passengers allowing for Seasonal affects*	Per cent of Total Passenger travellings by Air
New York-San Francisco	2,588	30,683	51,139	981	7,080	13.1
New York-Los Angeles	2,500	26,975	44,959	1,558	13,750	23.4
New York-Seattle	2,475	4,231	7,051	277	2,150	23.4
Kansas City-Los Angeles	1,392	6,970	11,616	149	1,325	10.2
New York-New Orleans	1,175	9,309	15,665	435	4,250	21.3
New York-St. Louis	888	28,023	46,705	966	8,520	15.4
San Francisco-Seattle	693	12,150	20,250	880	7,470	26.9
St. Louis-New Orleans	606	4,474	7,456	111	906	11.8
New-York-Detroit	486	73,787	122,979	3,689	33,600	21.5
Los Angeles-San Francisco	327	158,267	263,779	5,137	43,500	14.2
New York-Washington	214	578,484	964,140	13,105	125,000	11.5
New York-Boston	184	545,533	909,221	14,189	111,200	10.9
New York-Philadelphia	95	1,508,011	2,513,351	2,269	20,680	0.8

* As shown by indices determined for various routes in Air Traffic Survey of Civil Aeronautics Board, Sept., 1940.

I want to direct special attention to the number of short routes included in this tabulation. They offer the closest analogy between American and British conditions; and American experience contradicts the frequent presumption that the aeroplane is primarily a vehicle of long-distance transport, and that short routes can flourish only where water or some other exceptional obstacle to surface transport intervenes. It is true that aircraft offer the most impressive economy of time over long distances; but it is also true that more people want to travel for short distances than for long ones. Experience already proves that an impressive traffic can be developed between cities that are but an evening's railway journey apart. Even between New York and Philadelphia, about the size of London and somewhat larger than Birmingham, respectively, and no farther apart than those two cities, and with the best inter-city railroad service in the United States, more than 75 passengers per day were already being carried by air in 1940, exclusive of any transit passengers for whom the New York-Philadelphia flight constituted only a part of their trip.

During the period 1938-41, the volume of passenger movement by air within the United States was increasing at an average rate of a little more than 40 per cent. per year. Obviously no such rate of increase could be maintained indefinitely; but I see no reason why the airlines should not, within a very few years, be handling at least two-thirds of the total pre-war rail and air traffic over distances of 1,000 miles or more, and a quarter of the existing traffic on routes as short as 200 miles. Furthermore, there will be a substantial amount of additional passenger travel by those who will make long-distance trips that they cannot now spare the time to make at all; and over shorter distances a certain number of travellers who now prefer the private motor car to the rails will be won back to the common carrier by the superior speed and comfort which the airline can offer. The war is so changing economic structures and so altering the habits both of individuals and of industries as to make detailed prophecy of the post-war period very hazardous; and the actual attainment will, of course, be largely dependent upon the economic evolution of air transportation and the rates that it proves necessary to charge for air travel in the future; but it does not seem unreasonable to anticipate that passenger traffic by air over transcontinental distances will be as much as 120 per cent. of the total of the air and rail traffic between the same points in 1940; while over 200-mile distances a corresponding ratio might be around 50 per cent. There will, of course, be further increases in total traffic flow due to the addition of new points not now served.

Other things being equal, the amount of air travel is dependent on population and inter-city distance. In American experience, the number of passengers by air is roughly proportional to the product of the two populations connected and inversely proportional to the distance between them, at least for distances of 200 miles or more. London has a somewhat larger population than New York; Liverpool is about the size of Boston. The London-Liverpool distance is almost exactly equal to the New York-Boston distance; and if we may look forward with some confidence to handling an average of 2,000 passengers a day by air between New York and Boston, plus the transit traffic passing through those points, it would seem reasonable to expect that the London-Liverpool traffic would be of the same order.

With these predictions as a basis, I return to the problem of aeroplane size and airport capacity. From the general assumptions that I have indicated with respect to the growth of traffic between 1940 and the period immediately after the war, and upon the tentative hypothesis that a 20-passenger aircraft will be the smallest which can be operated with enough economy to compete with highly efficient surface transport, there would appear likely to be a post-war need for about 80 departures of aircraft of that size from New York between 5.30 and 6.30 each afternoon, flying to about 40 different cities as first points of call. With 40-passenger aircraft only about half as many departures would be needed. The problem of airport capacity would be relaxed; but about 25 of the 40 cities which could reasonably expect to have the advantages of non-stop connection with New York by the smaller aircraft would be likely to lose it with the larger. If on the other hand a mixture of 10-passenger, 20-passenger, and 40-passenger aircraft could be used, with the selection of equipment for each route depending on the amount of traffic, one may foresee a justification for about 15 departures of the largest type, 50 of the middle size, and 50 of the smallest, within the busiest hour of the day.

Of the passengers whom these aircraft would be carrying as they left New York, present experience indicates that approximately two-thirds would be travelling a distance of less than 400 miles, roughly corresponding to the radius covered by operations from London to points within the United Kingdom, France, Belgium, and the Netherlands. The population within a 400-mile radius around New York is 45,000,000; that of the United Kingdom about the same; and American experience with the growth of local traffic up to 1941, projected into the future, suggests that internal services alone will create a need for some 50 to 100 transport take-offs from London with aircraft of 20-passenger capacity or larger within the busiest single hour of the day. If the minimum usable size of the transport aircraft can be reduced to the 10-passenger level, the number of justified schedules, for London as for New York, should be nearly doubled.

In summary, I believe that certain general conclusions will apply either to London or to New York, or to any other city of large population.

(1) The number of points that can be given through service will vary very rapidly with the minimum size of aircraft that can be efficiently and economically used;

(2) The number of air transport schedules that will be needed during the busiest part of the day will seriously overtax the capacity of a single airport by existing standards;

(3) If future development should make it feasible to operate aeroplanes of as little as 10-passenger capacity on reasonable economic terms the number of schedules that would be justified and required would so increase that not only London and New York, but a number of smaller cities as well, would almost certainly need at least two or three independent airports for passenger transport service alone, quite apart from any provision that might be made for other classes of flying;

(4) The extent to which such duplication of airports will actually be required will depend upon the extent to which air traffic control is improved through the application of wartime experience, and in particular upon the accuracy and certainty with which pilots can be instrumentally advised of the location and distance and direction of movement of other neighbouring aircraft, which they cannot see, without being exclusively dependent upon communication of such information from the ground.

In connection with services between two cities within a few hundred miles of one another, there is practically no limit to the desirable increase in frequency. For the longer flights, it is unnecessary to be so ambitious. For a journey with an apparent duration of 12 hours, for example, measured from the local time of departure to the local time of arrival, there would be little occasion to schedule departures in the interest of through traffic at any hour between noon and 7.30 p.m. or between midnight and 8 a.m. Two or three schedules during the morning for evening arrival, and four or five during the evening for arrival during the following morning, ought to serve all purposes, regardless of the volume of traffic. If the number of travellers seeking accommodation promises to exceed what can reasonably be provided for with six or seven schedules a day with the type of equipment initially under consideration, it will be appropriate to consider the use of larger aircraft in preference to a further increase in schedules.

The relationship between frequency and size may also be regarded in the opposite sense, of determining the minimum size of aircraft compatible with a high degree of comfort and convenience to the passengers. As in the matter of frequency, there is no strict maximum here. If an aircraft in operation between London and Belfast were equipped with deeply upholstered divans and gymnasium apparatus and arrangements for the showing of moving pictures, the passengers would no doubt be delighted, but they can scarcely be said to suffer from the absence of such refinements. I am speaking as a passenger rather than as an engineer when I express a personal opinion that aircraft of about 20-passenger capacity provide a sufficiently comfortable ride on trips up to four or five hours' duration, and allow meals to be attractively enough served, so that no further increase in size is particularly important as an end in itself, if it has to be obtained at the expense of frequency. The accommodations for overnight travel furnished by machines in the 20-passenger category are on the other hand somewhat restricted. An aircraft of about double the floor area and seating capacity of the familiar DC-3 would be welcomed for trips lasting more than eight or ten hours. For longer flights still, such as that across the Atlantic, or even more certainly for substantially continuous day and night journeys between America and England and the Far East, one would like to have an amount of floor space and a variety of seating arrangements and other internal accommodation that would hardly be feasible, or compatible with economy, on an aeroplane of less than 100,000 lb. gross weight.

We must then consider, for any particular route, whether the amount of traffic likely to be available will be great enough to permit the realization of both the maximum reasonably useful frequency and the minimum reasonably satisfactory size, and at the same time to meet the requirements of economy of operation. If the volume of traffic does not promise to be up to the required level, we must decide whether frequency, spaciousness, or economy is to be sacrificed.

Such an analysis can be applied to the route in which we have a common interest, and upon which we shall shuttle to and fro in years to come—the route connecting America and Britain.

In the 12 months ended June 30, 1936, a total of 291,000 passengers arrived in the United States from Europe, while 276,000 made the opposite journey. Of those numbers, 74,000 and 55,000, respectively, were in the first and cabin classes. Canadian traffic would have made a substantial addition. The movement for the following year was somewhat heavier, but already influenced in its nature by

the shadow of coming war; and that for the best years before 1930 had also been substantially higher than in 1938 and 1939.

A substantial proportion of the tourists undoubtedly welcome the sea voyage for its own sake, and will prefer to keep it as a part of their holiday. The necessary length of the non-stop flight from easternmost North America to the British Isles imposes an economic burden which is likely to reflect itself in rates of fare considerably higher than those charged for covering the same distance in Continental air transport. Nevertheless I believe that it would not be too sanguine to anticipate that half of the maximum pre-war ocean travel in the first and cabin classes will be shifted into the air. Certainly the factor of newly-created travel will be an important one in this case; for just as statesmen and soldiers have learned in the past two years to run back and forth across the Atlantic when there is need of discussion, so in future business men of London or Birmingham having negotiations afoot in New York or Detroit will board a plane where once they would have sent a cablegram. It does not seem over-optimistic to anticipate that such newly-created travel over the Atlantic will equal twice the amount diverted from the previously existing channels.

There is another way of arriving at a figure for the volume of transatlantic air travel. In September, 1940, the average travel between the cities of the Pacific coast of the United States and those of the eastern third of the country averaged 250 passengers per day. I have little doubt that after the war the figure will be increased to 1,200. That represents the prospective interchange of persons between two regions, one of about 10,000,000 population and the other of about 90,000,000, with their centres of population located about 2,400 miles apart. In considering transatlantic traffic, on the other hand, we are reckoning with the interchange between populations of about 90,000,000 and 250,000,000, respectively —considering only the eastern third of North America and the western half of Europe as being major contributors to transatlantic movement—with their centres of population separated by about 3,700 miles.

Upon all those bases I believe it reasonable to anticipate a post-war average of 600 passengers by air per day in each direction between the United States and Canada and the British Isles and the Continent of Europe. The daily average will, of course, be subject to substantial seasonal fluctuations from the annual mean, unless we make even better progress than I expect in eliminating irregularities of service due to the weather.

Though less than half of the transatlantic passenger traffic before 1939 found its eastern terminal in the British Isles, the faithfulness with which aircraft can adhere to Great Circle routes, at least in summer, and the desirability of keeping the non-stop distance to a minimum, puts Britain in a more favourable position for providing the initial European point of contact for air routes than for shipping. Upon the assumption that the apparent time from London to New York will be 14 hours, which I believe is compatible with the conclusions that I shall later develop on the relation between speed, non-stop distance, and economy, a departure from London at six in the afternoon will permit arrival in New York at eight in the morning. Travelling in the other direction the corresponding apparent time, allowing for the higher speed with the prevailing wind, would be about 20 hours. It will be possible to fly must faster than that. I doubt that it will be sound commercial operating practice to do so in any period that can be foreseen in the very near future.

Upon that basis I can look forward to departures from London at 5, 6, 8, and 10 p.m. and midnight as offering as much frequency as anyone could reasonably desire. Allowing for flights that may start from points on the Continent, an all-inclusive year-round average of eight schedules each way each day between North America and Europe seems a reasonable goal.

It is a goal that may be attainable, if the total traffic reaches the figures that I have given as probable for the early post-war period. An average of 300

passengers per day in each direction, spread out among eight schedules per day, would put an average of 37 passengers on each aeroplane. Allowing for the 65 per cent. load factor which seems to be about the maximum that can be expected on any commercial service under normal peacetime conditions, that would call for an aircraft providing accommodations for 57 passengers. Such a machine would be large enough to provide the minimum degree of comfort that one would like to enjoy a trip lasting 18 hours or more; and it ought to permit a reasonably close approach to optimum economy of operation.

It is, of course, possible that two radically different types of service will exist side by side, giving different degrees of luxury of accommodation and speed at different rates of fare. It is possible that those who wish to remain in London for a couple of hours longer in the evening, and still arrive in New York at the same hour in the morning, will be able to accomplish their purpose by choosing a high-speed schedule at an extra fare. I believe, however, that the common disposition is to exaggerate the probable extent of these differences. The actual time saved by varying the speed of an aeroplane within what can be considered the range of possible commercial interest is so small, and the advantages of keeping to aircraft of reasonably large size on these long-range operations by concentrating loads are so great, that the systematic creation and maintenance of two or more different types of transatlantic passenger service with different types of aircraft seems somewhat unlikely unless governmental policies promote such a distinction. It does on the other hand seem altogether probable that two classes of service will be offered in the same machine, with materially lower fares available to those who are willing to contribute to a reduction of empty weight by accepting comparatively Spartan accommodations.

Some exception may be taken to my having discussed traffic entirely in terms of passengers. I have done so partly because the character and variety of the passenger accommodations are primarily dependent upon the number of passengers for whom accommodation is provided—partly because I believe that if the movement of cargo by air does show such development as to constitute a major proportion of the commercial loads moved it will be cared for, in large part, in aircraft handling cargo alone. Frequency would be less important in that case—although even for cargo a transatlantic departure in the early part of the afternoon and one in mid-evening would be desirable.

The Economic Consequences of Aeroplane Performance.

In undertaking an analysis of the economic effects of modifications in the fundamental characteristics of transport aircraft, I have taken existing operating costs as a starting point. Specifically, I have taken the costs of operating the Douglas DC-3 on major airlines within the United States during the spring of 1942. That aircraft has up to the present time been flown for over 400,000,000 miles in the United States alone, in addition to many millions in the present Anglo-Dutch operation between England and Lisbon and on routes in Continental Europe before the war. It is approved under American regulation for a maximum take-off load of 25,200 lb. In the normal seating arrangement it provides for 21 passengers, and over distances of 500 miles or less, permitting relatively light fuel loads, it can carry that number of persons together with from 500 to 1,000 lb. of mail and express. The cruising speed is a little over 180 miles an hour at 10,000 ft.

The median total cost for three of the leading airlines using DC-3's was reasonably stabilized at about 68 cents. per revenue-mile flown throughout the period 1939-41. For those early months of 1942 upon which my detailed analysis of costs is based, the figure was 68.7 cents.[2]

Each of the airlines of the United States makes a monthly report to the Civil Aeronautics Board, classifying its expenditures under approximately 180 titles.

[2] The exchange rate throughout the period to which these figures relate was 20 cents per shilling.

Many of the items are trivial in amount, and about ten per cent. of the number of titles account for nearly 60 per cent. of the total cost. The main groups, and some of the major items within the groups, are:—

Title of Account.	Median cost in spring of 1942 (cents. per revenue-mile).		Percentage of total cost.	
Pay of aircraft captains	6.23		9.1	
Pay of co-pilots	2.18		3.2	
Fuel (including taxes)	8.19		11.9	
Oil	0.37		0.5	
Accidental damage to flight equipment (including insurance premiums on such damage)	0.94		1.4	
Other flying operations expenses	1.33		1.9	
Total flying operations expense		19.24		28.0
Meteorologists and dispatchers	0.49		0.7	
Radio operators at ground stations	1.25		1.8	
Passenger and ticket agents at airports	2.51		3.7	
Service employees at airports (not including shop personnel)	2.83		4.1	
Other ground operations expense (telephone and telegraph, operation of motor cars, rent of buildings, etc.)	6.11		8.9	
Total ground operations expense		13.19		19.2
Aircraft repairs, labour	1.45		2.1	
Aircraft repairs, material and parts	0.78		1.1	
Aircraft engine repairs, labour	1.16		1.7	
Aircraft engine repairs, materials and parts	1.86		2.7	
Aircraft instrument repairs	0.15		0.2	
Aircraft propeller repairs	0.09		0.1	
Aircraft radio equipment repairs	0.37		0.6	
Total flying equipment maintenance, direct		5.86		8.5
Ground radio equipment repairs	0.21		0.3	
Repairs to buildings, tools and other ground mechanical equipment	0.53		0.8	
Other ground equipment repairs	0.11		0.2	
Total ground equipment maintenance, direct		0.85		1.3
Total equipment maintenance, indirect (general superintendence, storeroom employees, unallocated shop labour, telephone and telegraph, rental of buildings, office supplies, and public utilities used in connection with maintenance work)		3.44		5.0
Pay of cabin attendants	1.22		1.7	
Food service for passengers	1.88		2.7	
Passenger supplies (linen, etc.)	0.42		0.6	
Expense of caring for passengers (on interrupted trips)	0.25		0.4	
Passenger liability insurance	1.35		2.0	
Other passenger service expenses	0.87		1.3	
Total passenger service		5.99		8.7
Sales managers, agents and other personnel engaged in soliciting traffic	1.03		1.5	
Passenger and ticket agents and reservation personnel (in addition to those at airports already covered)	2.03		3.0	

Title of Account.	Median cost in spring of 1942 (cents. per revenue-mile).		Percentage of total cost.	
Agency commissions on tickets	0.35		0.5	
Other traffic and sales expense	3.37		4.9	
Total traffic and sales		6.78		9.9
Direct cost of newspaper advertising	0.56		0.8	
Direct cost of other advertising	0.15		0.2	
Publication of time-tables and circulars ...	0.14		0.2	
Other advertising and publicity expense ...	0.76		1.1	
Total advertising and publicity		1.61		2.3
Pay of general officers and executives ...	0.31		0.4	
Pay of general office employees	1.48		2.2	
Personnel, pensions, and welfare work ...	1.13		1.6	
General taxes	1.41		2.1	
Legal fees and legal expenses	0.18		0.3	
Other general and administrative expenses ...	1.13		1.6	
Total general and administrative expenses		5.64		8.2
Depreciation of aircraft	3.44[3]		5.0	
Depreciation of aircraft engines	0.85[3]		1.3	
Depreciation of aircraft propellers	0.35[3]		0.5	
Depreciation of aircraft radio equipment ...	0.40		0.6	
Total depreciation of flying equipment ...		5.04		7.4
Depreciation of radio equipment for ground stations	0.15		0.2	
Depreciation on tools and mechanical equipment	0.15		0.2	
Depreciation on motor cars	0.12		0.2	
Dépreciation on other ground equipment (buildings, furniture, and office equipment, etc.)	0.61		0.9	
Total depreciation on ground equipment ...		1.03		1.5
Total operating expenses		68.87[4]		100.0

I have adopted, with respect to each of the accounts that make up the total of expense, what seem appropriate assumptions regarding the variation of that particular cost with the speed of the aircraft and with its weight, total power, number of engines and wing area. For purposes of illustration, I list a few typical examples.

The pay of flight crews has been computed under the National Labour Board decision which established a standard in that matter for the airlines of the United States, except that I have plotted a smooth curve in lieu of the broken line which literally represents the Labour Board formula. The effect is that the pay received by pilots for each hour flown varies approximately as the square root of the speed, and the payment per mile flown is therefore approximately proportional to the inverse square root of speed.

Cost of fuel has been computed, with suitable allowance for consumption during taxying, take-off, and climb.

Seventy-five per cent. of the cost of aircraft maintenance has been taken as proportional to flight time, and therefore inversely proportional to speed, while the

[3] The figures given for depreciation of aircraft are computed for a five-year service-life. Depreciation costs actually being reported at the present time are distorted by the impossibility of securing new aircraft for several years past, and the consequent continued use of aircraft that are fully depreciated on the operators' books.

[4] British costs under pre-war conditions would differ from the American figures in that the item for fuel would be substantially higher, while a large proportion of the other items would be appreciably lower. American fuel costs are based on a price, including tax, of approximately 13 cents per U.S. gallon, equivalent to tenpence per Imperial gallon.

remaining 25 per cent. is assumed proportional to the number of landings and therefore independent of speed. Aircraft maintenance is assumed to be proportional to $W^{0.9}$, where W is the gross weight of the aircraft; and aircraft engine maintenance proportional to $P^{0.75}$, where P is the power of the individual engine, since there are many maintenance operations in which neither labour nor material cost is doubled by doubling the weight of the aircraft or the engine power.

Twin-engine aircraft are assumed to carry an operating crew of two in addition to the cabin attendants, while four-engine aircraft are credited with a flight engineer in addition to the two pilots. This, of course, holds only for operations over comparatively short distances.

The depreciation is in all cases based upon the assumption of a five-year life, and a flying time of 3,000 hours per year. It may be noted in passing that the major domestic airlines of the United States are at present averaging about 4,000 hours per year with each aeroplane, but to accomplish so high a level they are having to plan their schedules with primary reference to the availability of equipment, rather than to the desires of the travelling public. As soon as aircraft have reached the terminal and been given time for the necessary inspection and maintenance operations they are started off again, even though that involves scheduling some departures at hours when few people would normally want to travel.

The first cost of the aeroplane is assumed proportional to $W^{1.25}$, since increase in the size of aircraft almost inevitably leads to decrease in the number of units produced and consequent loss of certain production economies; and airframe cost has been assumed to undergo a further increase of 10 per cent. in passing from the twin-engine to the four-engine type, other things being equal. The first cost of engines, on the other hand, is considered as varying as $P^{0.75}$. The cost of radio equipment is assumed independent of the characteristics of the aircraft. That assumption may be unrealistic, since the installations for very large aircraft are habitually planned on a lavish scale; but I have assumed that all of the aircraft within the range of the present study will carry radio equipment fully adequate for all the problems of communication and navigation that their pilots will encounter, and presumably there is no occasion for providing more than that in any case. If the assumption be in error, the results of the error are unfavourable to the large aircraft. The same may be said of the assumption that radio operation on continental services will continue to be the function of the pilot and co-pilot, rather than an additional member of the crew to be carried in all cases. The determination of the size of the smallest aircraft that can be used in transport is going to depend very largely on the amount of radio and instrumental equipment that will be needed for safe and regular operation in the post-war period, and upon the size of the crew required to operate the equipment and take advantage of its indications.

From this sub-structure of tabulation, assumption, and formula I have proceeded to analysis of the effects of specific characteristics on cost. The analyses are of course dependent on the assumptions, and a different set of assumptions would produce a different set of conclusions. I must therefore offer my own conclusions with a reservation that they are all based on my own opinion with respect to a large number of underlying factors; but substantial variations could be made in a considerable number of the individual elements entering into the computations without causing any radical change in their general indications. The results of the first such analysis are presented in Fig. 1, and show the relation between cost per pay load ton-mile and aerodynamic fineness in an aeroplane which in all other respects retains the characteristics of the DC-3. My computations were based on the ton of 2,000 lbs., which is always used for such purposes in the United States, and to correct these and all subsequent ton-mile figures into conventional British units the values will need to be increased by approximately one-eighth. Since the cost had in any case to be based upon American price levels it seemed best to keep to American units throughout, both in currency and in weight.

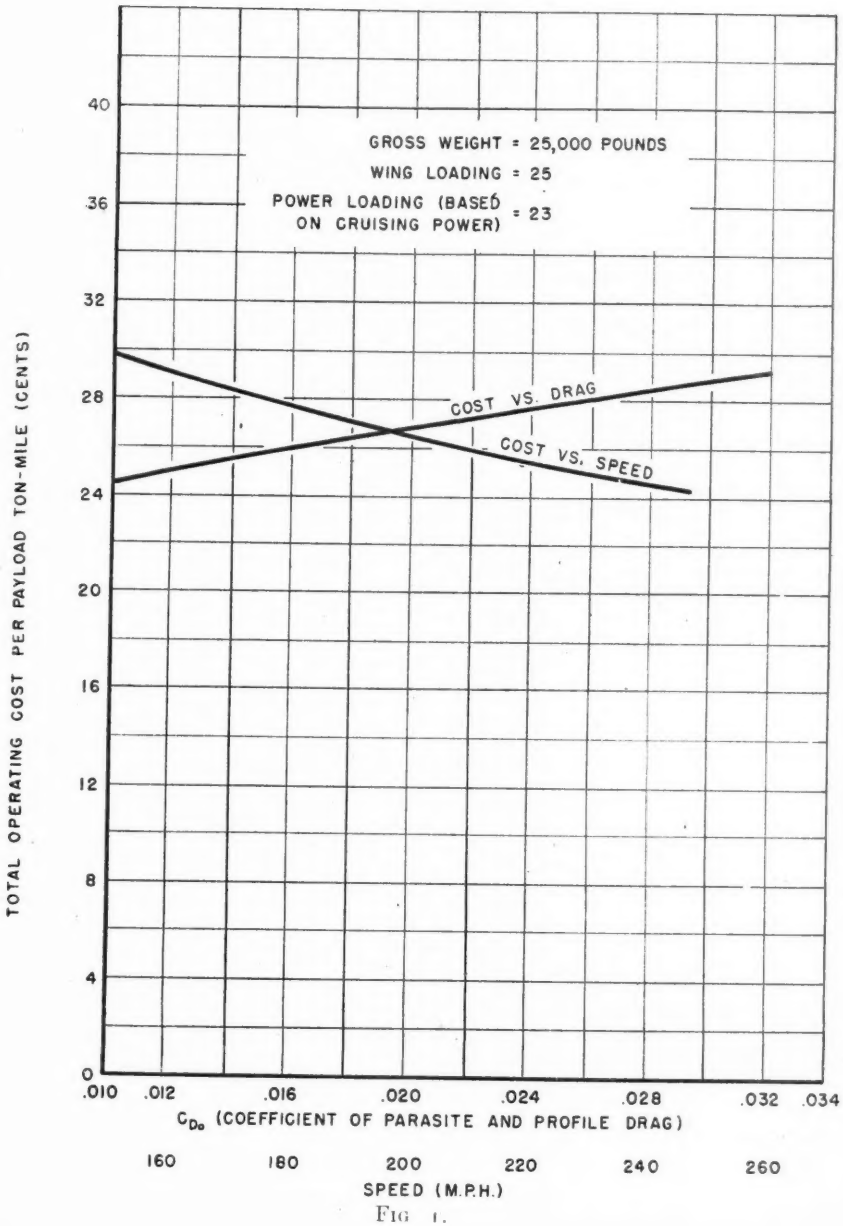

GROSS WEIGHT = 25,000 POUNDS
WING LOADING = 25
POWER LOADING (BASED ON CRUISING POWER) = 23
COST VS. DRAG
COST VS. SPEED
TOTAL OPERATING COST PER PAYLOAD TON-MILE (CENTS)
0
4
8
12
16
20
24
28
32
36
40
.010
.012
.016
.020
.024
.028
.032
.034
C_{D_o} (COEFFICIENT OF PARASITE AND PROFILE DRAG)
160
180
200
220
240
260
SPEED (M.P.H.)

FIG 1.

In this case, as in all of those which follow in this section of my lecture, operation over relatively short distances, not to exceed 600 miles without stop, has been contemplated. The curve is plotted on the assumption of a constant payload of 5,000 lb., or 20 per cent. of the gross weight of the aircraft; but I believe that assumption substantially corresponds to actual conditions in operating over short or moderate distances, since the reduction in required fuel load that results from a reduction of drag is substantially offset by the increase in the required load factor that comes with increase of speed, and the consequent necessity of increasing structural weight. The amount remaining available for payload remains substantially constant.

The curve is a comparatively flat one. Increase of fineness increases the cruising speed that is compatible with reasonable economy; and at the same time, in place of the increase in operating cost which normally accompanies an increase of speed secured by use of more power, the cost is somewhat reduced. To put the indications of the curve into a simple approximate rule, it appears that where the speed can be increased 10 per cent. by reducing the drag, without changing the power loading or wing loading, the operating cost per ton-mile is reduced by approximately four per cent.—as though 40 per cent. of the total expenses of operation were inversely proportional to speed, whereas 60 per cent., including most of the commercial expenses and ground operating expenses, were independent of that factor. Saving in fuel costs represents approximately one-fourth of the total effect on speed on cost—saving in depreciation approximately one-quarter of the remainder.

Size and Unit Cost.

The next step, represented in Fig. 2, is the analysis of the effect of size. Wing loading, power loading, and ratio of payload to gross weight are again assumed constant; but account is taken of the improvement of aerodynamic fineness that naturally accompanies increase in size. In determining the variation of drag coefficient I have assumed that profile drag of the wing will increase in proportion to $W^{0.9}$, and the total drag of fuselage and nacelles in proportion to $W^{0.6}$. The assumption may be a little on the optimistic side within the range with which we are most likely to be concerned in practice, for it represents substantial acceptance of the popular approximation that the linear dimensions of a transport fuselage need vary only as the cube root of the amount of payload, and also includes some allowance for gain with increase of Reynolds Number. Unfortunately, however, passengers cannot be stowed in fractional layers, and the transition from the aeroplane with a single floor in the cabin to one with two floors is therefore abrupt. It is not likely to occur short of a weight of at least 80,000 lb., and up to that point it is the floor area of the cabin, rather than the volumetric capacity of the fuselage, which must be kept directly proportional to passenger payload.

The assumption of a wing loading as low as 25 lb. per square foot in very large aircraft is an unlikely one; but the object at this point is to segregate the direct effect of changes in size from the effects of any other variables. The influence of wing loading will be separately examined.

The curve of cost against weight flattens as the weight increases, and would appear for the four-engined aeroplane to be asymptotic to a value of about 21.5 cents per payload ton-mile. An increase of gross weight from 20,000 to 30,000 lb. promises to reduce unit cost in short-distance operation by about 8 per cent.; whereas an increase from 100,000 lb. to 150,000, on the same methods of calculation, would effect only about a 3 per cent. decrease in cost per ton-mile. Doubling the gross weight of the aircraft promises typically to increase the speed for a given power loading by about 5 per cent. About one-quarter of the change in unit cost with size is attributable to the direct effect of this increase in speed; while the remainder is accounted for by such items as pay and expenses of

flight personnel, maintenance and depreciation on radio equipment and instruments, and others of which the total amount is either quite independent of the size of aircraft or varies much less rapidly than the size.

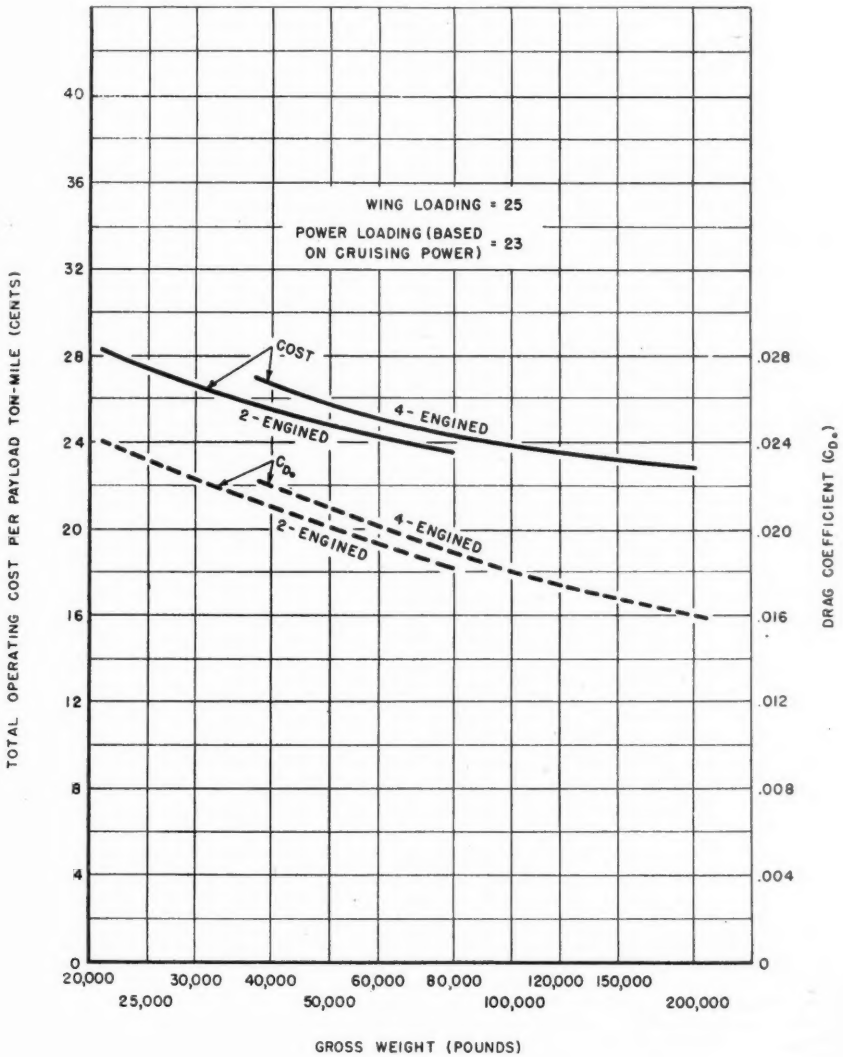


FIG. 2.

Although I have carried the curve to the left only to a weight of 20,000 lb., it is clear from experience as well as from theory that its slope continues to increase with further reductions in weight. That rapid increase of unit cost with decrease of size, when operations are conducted in accordance with present air transport practices, promises to constitute one of the great problems of the post-war

period. I have already spoken of the advantage for local services of being able to use aircraft of small size; but it is not a wholly favourable prospect; and it presents some questions in connection with the drafting of safety regulations of which I shall have more to say.

Under the assumptions that I have adopted as seeming most reasonable, it is necessary that a four-engine aeroplane should be approximately 40 per cent. heavier than a twin-engine one, assuming equal wing loading and power loading in the two cases, in order that the operating costs per ton-mile should be identical.

In this connection the possibilities of making a notable further reduction of drag by the total elimination of the fuselage and tail surfaces in aircraft of very large size should be considered. The classic reference on that subject is Dr. Roxbee Cox's Wilbur Wright Lecture of three years ago.[5] In an analysis to which I shall make no attempt to add, he concluded that the effective use of the flying-wing type of aircraft for the carriage of commercial passengers would be limited to aircraft of a gross weight of 350,000 lb. or more. In an aeroplane designed to carry only cargo, of relatively high density, the flying-wing form could be used in substantially smaller sizes—particularly if only very low speed were sought and a light wing loading were therefore permissible. Such a machine might reasonably have a cruising speed, at a given power loading and wing loading, about 10 per cent. higher than that of an aircraft of the same gross weight and of conventional form. Such an increase in speed, superposed on the direct effect of increase of size, ought to give to a 400,000 lb. flying wing a cruising speed at a given power loading approximately 20 per cent. higher than that of conventional aircraft of 60,000 lb. gross weight, and an operating cost per ton-mile approximately 20 per cent. lower than in a 60,000 lb. machine, provided that the percentage of payload for the very large aeroplane can be kept as large as for the medium-sized one.

Wing Loading and Power Loading.

The size of the aircraft used on a particular route will be determined largely by the amount of traffic available and by those considerations of passenger preference which I have previously discussed. The designer is to be relied upon to keep the drag coefficient as low as he is able, compatibly with the avoidance of unduly high production cost or the use of practices that would create undue difficulties in servicing or maintenance. The major variables at his disposal in planning the general form and performance characteristics of the aircraft are wing-loading, wing-form, and power loading. However spectacular the innovations of future years may be, and however ridiculous they may make our present predictions appear, as long as aeroplanes continue to depend upon the dynamic lift of a wing moving through the air they will continue to have a wing loading and span loading, and profile and induced drag therefrom. They will continue to have a power loading, and it will continue a primary factor in determination of both performance and economy; and the designer will still have to apply his discretion to choosing the optimum values of those ratios.

Increase of wing-loading has been steady since that day at Kitty Hawk nearly 40 years ago. The Wrights' first flight was made at a loading of approximately 1.5 lb. per square foot; and in Fig. 3 I have shown the general trend from that time to the present. The form of the curve before 1920 relates principally to military reconnaissance machines, that since 1920 relates to transport aircraft. In recent years the average long-term rate of increase has been about 1.5 lb. per sq. ft. per year.

I have a special interest in the study of wing loading in transports through my present official connection; for it is generally true that airworthiness regulations have a great effect upon the maximum wing loading that can be used. Designers

[5] "Looking Forward" by H. Roxbee Cox. Journal of the Royal Aeronautical Society, September, 1940, pp. 712-717.

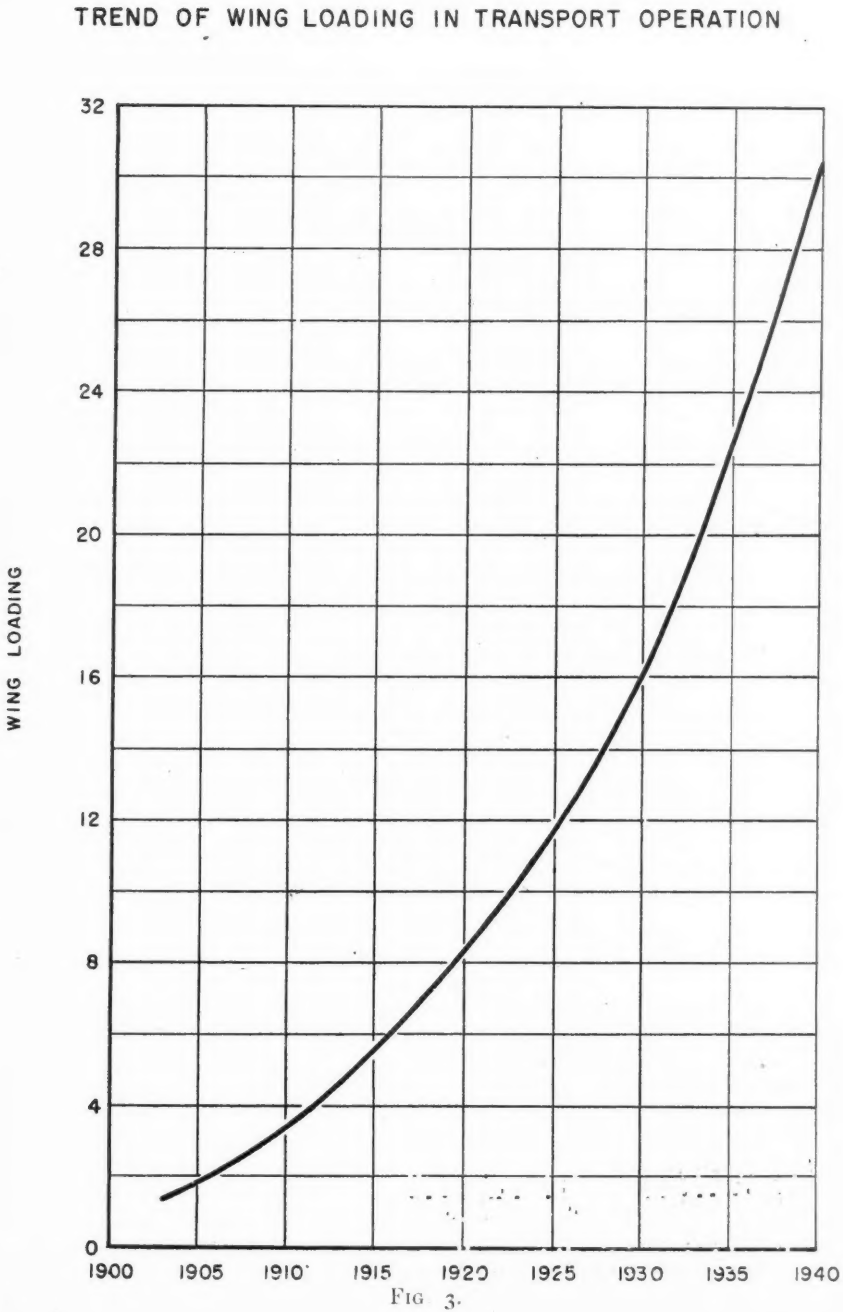

TREND OF WING LOADING IN TRANSPORT OPERATION
WING LOADING
32
28
24
20
16
12
8
4
0
1900
1905
1910
1915
1920
1925
1930
1935
1940

FIG 3.

sometimes reproach us with an over-conservative and an unduly restrictive attitude in that respect.

The chief engineers of several American companies have been good enough to respond to an inquiry concerning the wing loading that they would think it desirable to use in transport aircraft at the present time if no regulatory restrictions had to be considered. Although there are wide variations in individual opinion, the choice seems typically to fall around 30 lb. per sq. ft. for an aeroplane of 25,000 lb. gross weight; around 35 lb. per sq. ft. for a 60,000 lb. machine; and around 45 lb. per sq. ft. for one of 150,000 lb. These average figures, with the exception of the last, are well within the range of practicability under existing American airworthiness requirements; but some of the designers proposed values of which that would not have been true. It is generally agreed that wing loading should increase with gross weight, but some views favour an increase as rapid as the cube root of the weight, while others prefer only about half that rate of variation, or even less. The majority favour a higher initial wing loading in an aircraft designed especially for a long-range operation than in one of similar size intended for short flights; but the differences generally recommended are so small that the mean wing loading during the flight, allowing for half of the fuel load having been consumed, would be lower in the long-range machines.

As a preliminary step I have examined the plan form of the wing. Since the wing acts as a beam transmitting load along the span, it might reasonably be anticipated that when the plan form is changed the root depth of the beam would remain substantially in a fixed relationship with the span. It has been the common rule for a number of years that the maximum thickness of the wing at the root is about 3 per cent. of the span, with a few designers departing from the average by persistently favouring a ratio of between 3.5 and 4 per cent. There seems to be no present indication of any change in that respect, and a thickness of 3 per cent. of the span may be taken as the typical standard.

Upon that basis, and assuming a taper ratio of 3.0, the airfoil thickness ratio of the root section of the wing, in per cent., will be twice the aspect ratio. With a taper ratio of 2.0, the ratio of the airfoil thickness ratio at the root section to the aspect ratio of the wing will be 2.25.

With a relation established between wing thickness, aspect ratio, and thickness ratio, the aspect ratio which will produce minimum wing drag at any particular value of the lift coefficient can be determined for any given series of airfoil sections. Plotting minimum drag at optimum aspect ratio and thickness ratio against lift coefficient, in turn, the variation of wing drag with wing loading is derived. The curves presented in Fig. 4 happen to be based on an early NACA series. The aspect ratio for minimum drag has a value that increases only a little less rapidly than in direct proportion to the lift coefficient. The optimum span is therefore almost independent of the operating value of the lift coefficient, or, for a given cruising speed, of the wing loading.

In the particular case plotted the minimum drag corresponded to a lift coefficient of 0.54, an aspect ratio of 11.3, and a root thickness ratio of 0.23.

Improvement in the drag characteristics of airfoil sections operates to reduce the optimum value of the lift coefficient as determined by an analysis of this type, since reduction of drag makes it profitable to accept the profile drag that comes from increase of area rather than the induced drag that accompanies increase of lift coefficient. It is impossible to speak freely of the characteristics of modern low-drag sections; but on the assumption that all profile drag coefficients were reduced 50 per cent., as compared with those used in plotting Fig. 4, the optimum lift coefficient for minimum cruising drag would become 0.40 and the optimum aspect ratio 12.0.

It may be noted as a rough-and-ready rule that the wing loading for minimum wing drag at cruising speed with present-day airfoils should be approximately

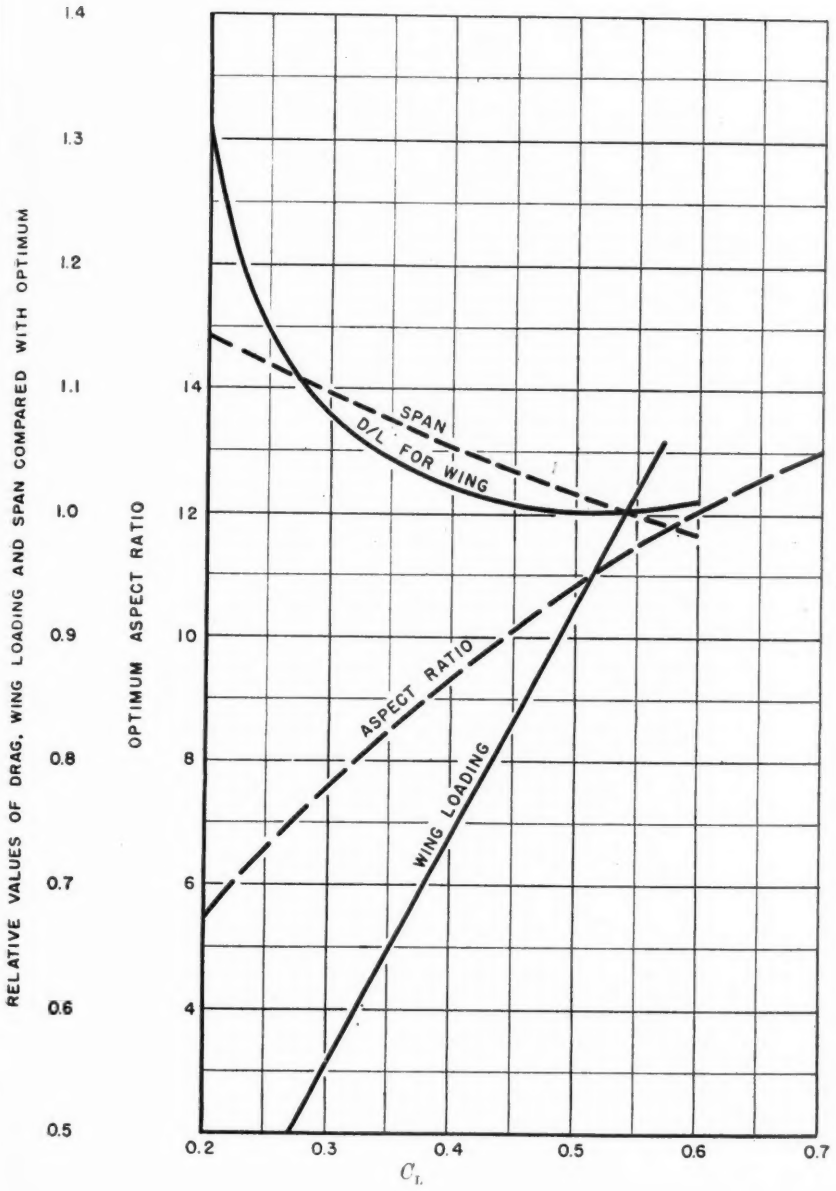

RELATIVE VALUES OF DRAG, WING LOADING AND SPAN COMPARED WITH OPTIMUM
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
OPTIMUM ASPECT RATIO
14
12
10
8
6
4
SPAN
D/L FOR WING
ASPECT RATIO
WING LOADING
0.2
0.3
0.4
0.5
0.6
0.7
C_L

Fig. 4.

$9(V/100)^2$, where V is the cruising speed in m.p.h. at a height of 10,000 ft., and that the span loading should be approximately $0.8(V/100)^2$.

The curve of drag against aspect ratio is very flat in the neighbourhood of its minimum value, and the curve of drag against lift coefficient almost equally flat. I believe the beneficial effect of very high wing loading on drag is often overestimated. There are, on the other hand, obvious structural advantages in reducing the aspect ratio and increasing the wing loading, both in direct saving of structural weight and through reduction of the required gust load factors. The reduction of wing loading by one-third, as compared with the optimum value, should increase the wing drag by barely 5 per cent.; but it will typically increase the weight of the wing by nearly 20 per cent., with some increase in the weight of other structural elements as well, and it is there that the price has to be paid. Where take-off quality and rate of climb are of paramount importance, improvements in those characteristics may offset the increase in structural weight that comes with increase of aspect ratio. No generally applicable balance can be struck between the aerodynamic and the structural factors; but it seems unlikely that there will be any appreciable gain from increasing the wing loading to above $10(V/100)^2$, or span loading to above $1.0(V/100)^2$, where V is again the cruising speed at 10,000 ft. For twin-engine aircraft, for which climb with one engine inoperative is a critical condition, the span loading is better kept down to $0.9(V/100)^2$. With airfoil sections of the future these optimum values may be reduced by from 10 to 25 per cent.; and they will, of course, be reduced by any increase in cruising altitude.

Combined Effect of Wing Loading and Power Loading.

Wing loading and power loading remain as variables. In the next series of charts I have examined the variations of speed and costs in terms of those factors. The basic aeroplane for this series of studies is a four-engine machine of 60,000 lb. gross weight, taken as approximating the size that is likely to be must used in overland operations between major centres after the war. In addition to the reduction of parasite drag that would naturally accompany the increase in size from the 25,000 lb. of the DC-3 to more than double that weight, the drag coefficient has been assumed to be reduced by approximately 20 per cent. from the DC-3 level. Specifically, the 60,000 lb. aeroplane, which would require a circular fuselage of between 11 and 12 ft. in outside diameter, is assumed to have a total parasite drag coefficient, excluding wings and tail surfaces, of 16.0—or, to use units more commonly employed in England, a parasite drag with wings and tail excluded of 190 lb. at 100 ft. per second.

Subject to these conditions, Fig. 5 shows the cruising speed that may be anticipated at 10,000 ft. altitude. In this chart as in the subsequent ones the power loading is based on cruising power, which is assumed to be one-half the maximum take-off power rating of the engines.

In computing the variation of costs with wing loading and power loading, the assumptions previously made have been supplemented by another set bearing on the effects of wing loading, such as that one-third of the first cost of an airframe is proportional to wing area; ten per cent. is proportional to the installed power; and the remainder to the gross weight.

The calculation of a considerable number of trial cases shows extraordinarily little difference in operating cost per ton-mile of gross weight of the aircraft, within the range investigated. The savings due to increase of speed are substantially offset by the increased costs due to increase of power. Of what change there is, about three-quarters is due to the increase of fuel cost with reduction of power loading. The results are shown in Fig. 6. Values in that chart are again given in terms of cents per payload ton-mile, to maintain consistency with the previous practice, although the payload in this case is a purely hypothetical one, taken uniformly at 20 per cent. of the gross weight.

POWER LOADING (BASED ON CRUISING POWER)

The next chart (Fig. 7) shows the variation of payload over a 500-mile distance with power loading and wing loading. Here for the first time really substantial differences begin to appear, and the real source of the economic penalty on low power loading or unduly light wing loading becomes apparent. The major variables controlling payloads in short-range operations are wing weight and

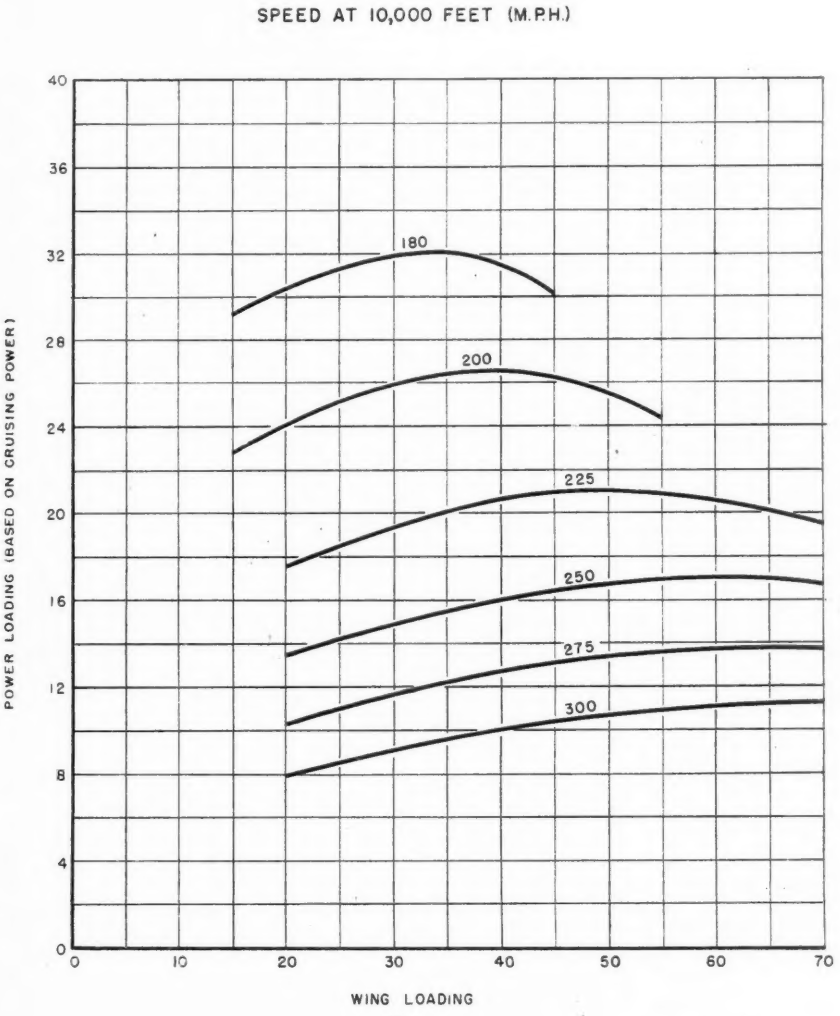


FIG. 5.

power plant weight. In computing structural weights, I have allowed for the variations of gust load factor and then assumed that in the case of the wing, for example, the weight varies as the load factor to the 0.75 power, the span to the 0.6 power, and the area to the 0.4. The ultimate load factors corresponding to a 30-ft. gust, encountered at 1.25 times cruising speed, range from

approximately 5.6 with minimum power loading and wing loading to 3.0 or less when both figures are at their maximum. A load factor of 3.75 has, however, been taken as the minimum allowable in any case, to allow for manœuvering load; and on that basis the manœuvering loads are generally more critical than the gust loads when the wing loading is above 45 lb. per sq. ft. The total power-plant weight, including the propeller and all accessories, has been taken as 2.25 lb. per take-off horsepower when the maximum take-off rating of each engine is 1,000 horsepower, decreasing to a weight of 2.00 lb. per horsepower in the

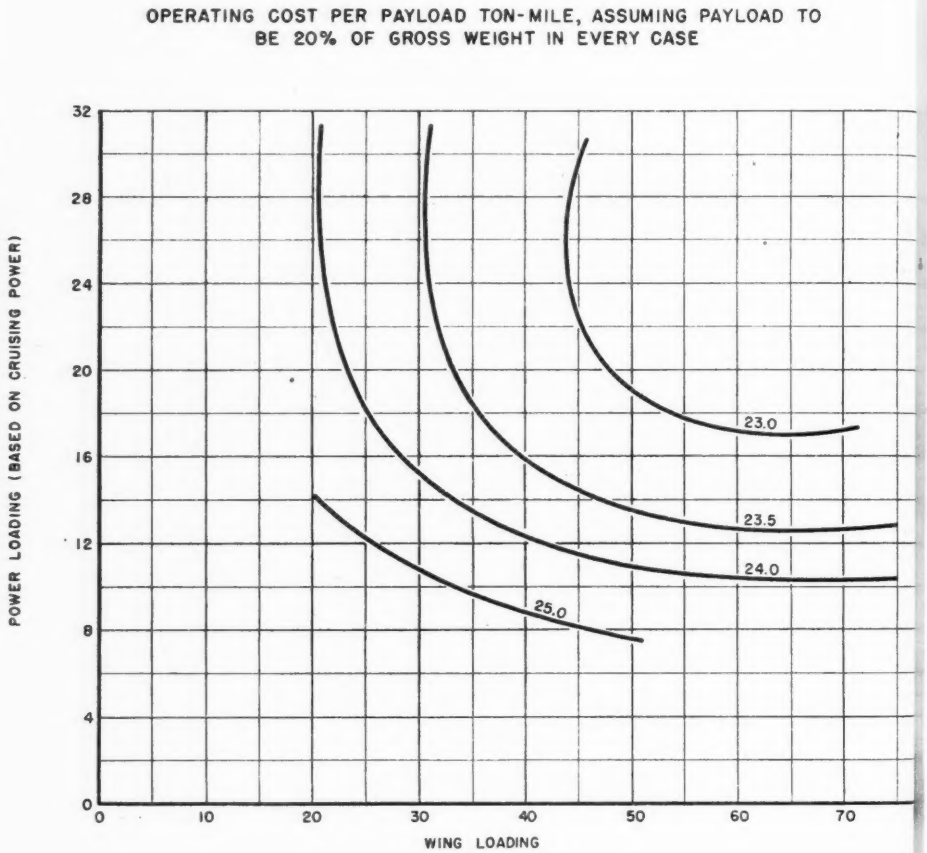


FIG. 6.

imagined, though as yet unrealised, case of power-plants of 3,000 horsepower each.

The weight of passenger accommodation, including that proportion of such items as sound-proofing and electric lighting which can be regarded as proportional to the number of passengers, is assumed to be 75 lb. for each passenger. That is an optimistic figure. It assumes that the luxury of post-war accommodation, at least on short flights, will be no greater than that of present aircraft. It would be quite easy to run the weight of passenger accommodation up to

double the figure used, and thereby to reduce all the payload percentages plotted in Fig. 7 by 20 per cent. or more.

The fuel load is based on a 500-mile range, with enough reserve to reach the destination against a 40-mile wind, to fly another 200 miles thereafter to reach an alternative field in case the point of intended landing proves to be closed in at the last minute, and then to cruise for another hour and a half at minimum power waiting for better weather or for its clearance from the traffic control. The

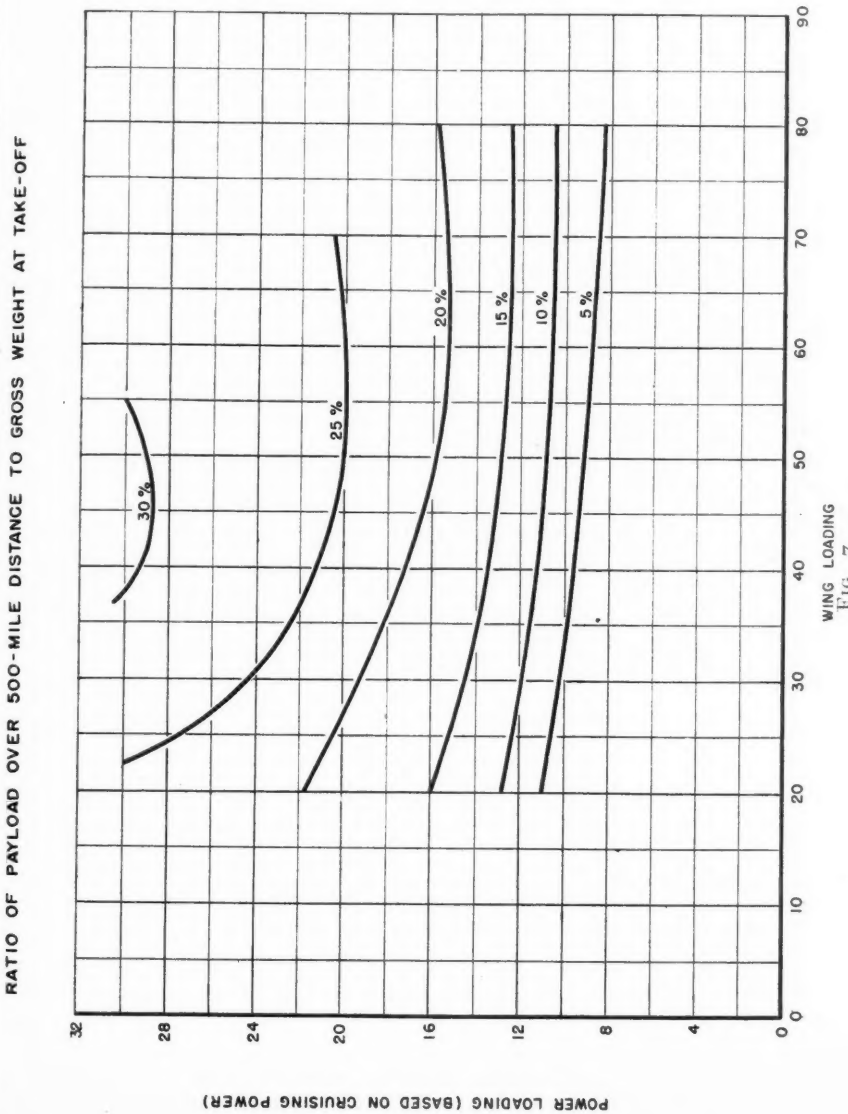


FIG. 7.

assumptions may seem strikingly conservative, but they include no more of an allowance for contingencies than is considered desirable in practice. Too many analyses of future possibilities have been made without allowance either for fuel reserve, for headwinds, or for extra consumption in take-off and climb. The ratio of fuel load to take-off weight on the conditions indicated, and with a specific consumption of 0.45 lb. per horsepower hour, ranges from 10.0 per cent. with a power-loading of 30 lb. per horsepower to 16.2 per cent. with a power-loading of 10, assuming the most advantageous wing loading to be used in each case.

OPERATING COST PER PAYLOAD TON-MILE (IN CENTS) BASED ON ACTUAL PAYLOAD CAPACITY OVER 500-MILE DISTANCE

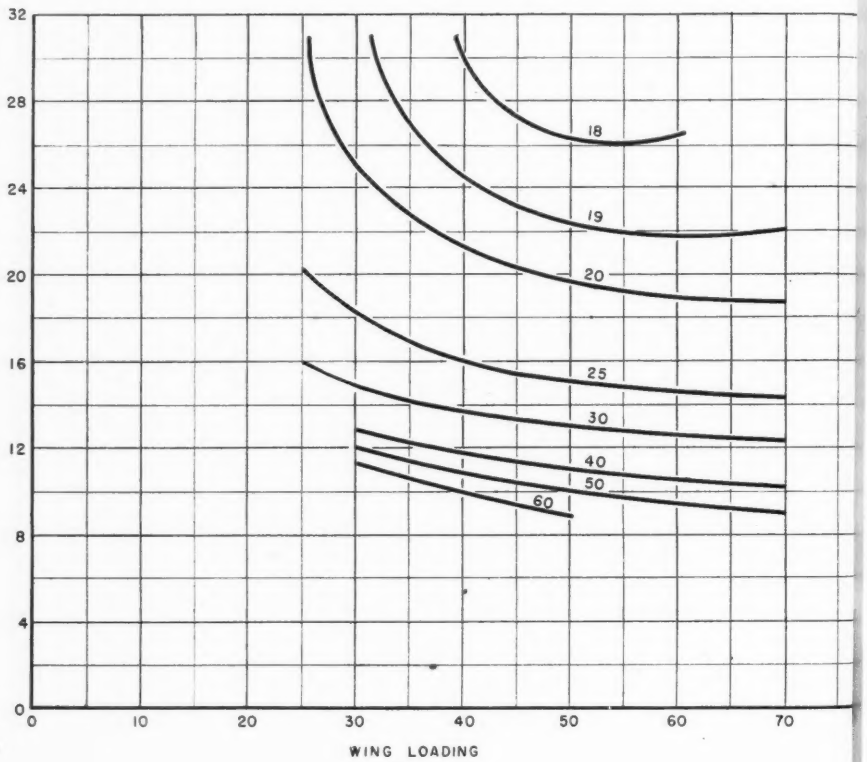


FIG. 8.

The extreme variation of structural weight within the confines of the chart is from 26 to 36 per cent.; that of fuel weight, as previously noted, from 10 to 16; the variation in weights of furnishings and equipment is almost negligible. The power-plant, however, ranges from 15 to 40 per cent. of the total, and its variations dominate the determination of the amount remaining for payload.

In combining the last two charts to produce Fig. 8, where cost per payload ton-mile is presented in terms of actual payload rather than of a hypothetical

fixed percentage of the gross weight, calculations have been revised to maintain a payload of 12,000 lb. as the constant element and allow the gross weight to vary. Suitable allowance has been made for the inherent effect of changes in size upon economy. The upper part of Fig. 8, corresponding to high power loadings, therefore represents aircraft of somewhat less than 60,000 lb. gross weight. The

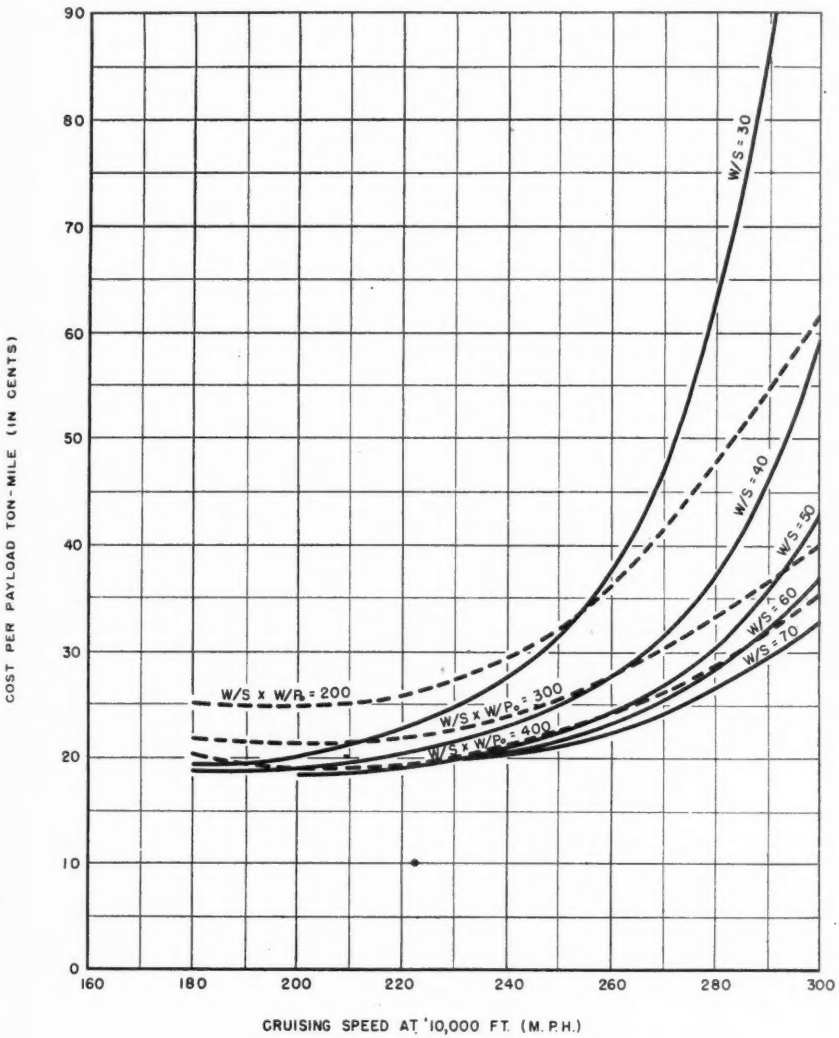


FIG. 9.

lower part, where the power loading is low, represents the economic performance of aircraft of substantially more than 60,000 lb. gross, in order that their relatively small percentage of payload may be built up to a total payload of 12,000 lb.

It is obvious that costs computed in this fashion are making asymptotic approach to a minimum, of the order of 17 cents per payload ton-mile, as the power loading is increased.

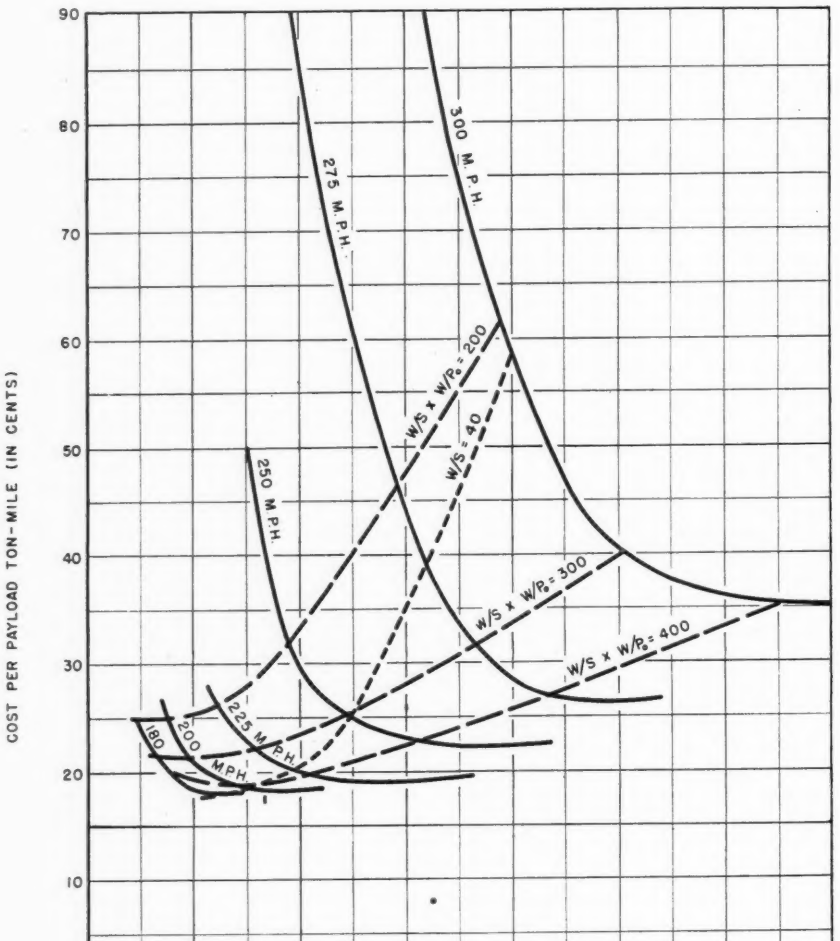


FIG. 10.

In Figs. 9 and 10 the data from Fig. 8 have been re-worked. In the former, costs are plotted against speed for various assumed limiting design conditions. Curves are drawn for several wing loadings and for several values of the product of wing loading by take-off power loading, which is a rough criterion of take-off

quality. As an aid to evaluating the significance of the latter group of curves, it is noted that the product for the DC-3, at the maximum take-off load allowed in regular transport operations in the United States, is 268; and that values of the product of 200, 300, 400, and 500 typically correspond, in the best present state of the art, to full-power take-off distances of about 1,200, 1,800, 2,400, and 3,100 ft., respectively, to reach a 50-ft. altitude from a standing start in still air.

On the assumptions that have entered into the preparation of these curves, there should be no appreciable economy from the adoption of a cruising speed of less than 200 m.p.h. unless the wing loading is to be limited to less than 35 lb. per sq. ft. Higher speeds than that are compatible with a close approximation to maximum economy only if the wing loading is to be increased with speed rapidly enough to keep it reasonably close (at least within 20 per cent.) to the value of $10(V/100)^2$, already suggested as constituting an approach to the optimum.

If the take-off quality be the criterion, the maximum economy for a given take-off performance appears to be secured at about 200 m.p.h., with an increase of cost per ton-mile of about 25 per cent. as a penalty on operating at a cruising speed of 250 m.p.h., and a 100 per cent. increase of cost when the cruising speed is raised to 300 m.p.h. A penalty of about a one-third increase in cost accompanies a reduction in take-off distance (to a 50-ft. altitude) from 1,800 to 1,200 ft.

In Fig. 10 the basic curves show the relationship between unit operating cost and the ratio of take-off power to wing area for various cruising speeds, thus eliminating weight as a direct factor. For purposes of comparison it may be noted that the ratio of take-off power to area in the DC-3 is 2.4; and that in present-day bombers it is typically about 4.0, and in fighters about 7.0. If a cruising speed of 200 m.p.h. at 10,000 ft. is a fundamental requirement, it appears that it would be obtained most economically by installing a take-off power of about 3.8 times the wing area; but that the full-power take-off distance under that condition would be about 3,000 ft. to reach a 50 ft. altitude. If the conditions of take-off are such as to limit the take-off distance to 1,800 ft., take-off power and wing area should be readjusted to make the former only 1.9 times the latter. The operating cost per payload ton-mile would then exceed the theoretical minimum attainable cost by about 15 per cent. It will be observed that in general, for any cruising speed, the difference between the minimum cost attainable with an indefinitely high value of the product of power loading and wing loading and the cost which corresponds to a value of 400 for that product is extremely small—substantially less than 10 per cent. This is equivalent to a statement that there is little economic benefit to be gained from designing for a full-power take-off distance of more than 2,400 ft. to a 50-ft. altitude.

If a cruising speed of 250 m.p.h. is desired, and is again subject to a take-off condition limiting the product of wing loading and power loading to 300, take-off power should be 4.9 times the wing area. To follow the same curve of take-off performance upward to its intersection with the curve that represents a cruising speed of 300 m.p.h. is to pass completely out of the realm of present reality, with a wing loading of 55 lb. per sq. ft. and a take-off power loading for the resultant transport that would closely approach the best that has so far been realized in a fighter.

In concluding this discussion I must emphasize that its conclusions apply only to a choice of characteristics for a new aircraft, to be planned with no more structural weight than is required for a proper margin of safety with the load that is to be carried, and to have no more space in the fuselage than is needed to accommodate that load. Obviously a different set of conclusions will be reached if there is already available an aircraft which has more strength, more margin of power, and more load-stowing capacity than it really requires for its present operating conditions, and if the problem is that of analyzing the effect on operating

cost and performance of increasing the permitted gross weight. In that instance the increase in gross weight is unaccompanied by any increase either in structural weight or power or fuselage size and drag, and almost all of the increase in gross appears as a net addition to payload. That case sometimes arises—especially where it is necessary to operate a particular type of aircraft with substantial variations in gross load to meet varying airport conditions—but it is not the case that I am considering here.

Further Opportunities for Saving Costs.

A reduction of 33 per cent. in wing profile drag, accompanied by a saving of about 20 per cent. in residual parasite drag, would seem to be enough of a possibility within the next few years to justify serious consideration of its effects. Such a reduction would increase the cruising speed at 10,000 ft. by from 10 to 15 per cent., the relative gain increasing with increase of power loading. The effect on cost at a given power loading, after allowing for the increase in empty weight that would accompany the rise of load factor due to the higher speed, would be small, and might even be adverse; but the unit cost at a constant speed and constant take-off run would be reduced by about 10 per cent. at 200 m.p.h., or 20 per cent. at 300.

This and other effects of possible future improvements in detail are assembled in a tabulation. The figures given are, of course, approximations of a comparatively crude order; but they at least serve to differentiate the major possibilities of improvement from the minor ones.

Actual change in characteristic.	Resultant reduction of operating cost (per cent.) (assuming the same cruising speed maintained after change as before) At 200 m.p.h. at 10,000 ft.	At 300 m.p.h. at 10,000 ft.
33 per cent. reduction in profile drag of wing, together with 20 per cent. reduction in parasite drag excluding wing	10	20
5 per cent. increase in propulsive efficiency ...	3	10
10 per cent. reduction in specific fuel consumption	3	10
10 per cent. reduction in unit weight of power plant	4	15
10 per cent. reduction in structural weight ...	6	12
10 per cent. reduction in weight of passenger accommodation	3	3
20 per cent. reduction in first cost of airframes	2	2
20 per cent. reduction in first cost of engines	1	2
20 per cent. increase in operating time per aeroplane per year	2	2
20 per cent. reduction in airframe maintenance cost	1	1
25 per cent. reduction in engine maintenance cost	2	4
50 per cent. reduction in accident hazard ...	3	3
40 per cent. reduction in ground operating expenses per ton-mile operated	8	7
33 per cent. reduction in general and administrative expenses per ton-mile operated ...	3	3

The amounts of increase or reduction assumed in the various quantities correspond to ratios of change that I believe there may be at least measurable hope of attaining within the next few years. The basic calculations on all these

rates of change of cost were made for an aeroplane having a payload capacity of 12,000 lb., with a mixed load of passengers and express. In general, however, the relative effects on cost will not vary greatly with size of the aircraft.

Though by no means all of the possible improvements listed will be realised in the period immediately following the war, a substantial number of them will be. At least I look forward with reasonable hope to the realization of enough of these gains to produce an aggregate saving of 15 per cent. in operating cost, assuming general price levels equal to those before the war. That would correspond to realizing about one-third of the tabulated gains under all the factors listed in the table, for the 200-mile case.

Cost of Carrying Cargo.

The extensive use of aircraft for moving urgent military cargo during the war has aroused an immense interest in the possibilities of a similar use for commercial shipments. Discussion has abated the more romantically optimistic visions of a future in which surface transport would have ceased to exist; and it is now accepted as axiomatic that the aeroplane must compete for goods, as it does for passengers, upon the basis of a balance between the special value of the service that is rendered and the magnitude of the special charge that is made for rendering it.

From the previous discussion it appears that the minimum cost actually realizable in the present state of the art, with an aircraft carrying a payload of 12,000 lb., is about 20 cents per ton-mile for the moving of loads composed in major part of passengers. Increasing the proportion of goods in the load, or operating aircraft carrying goods alone, has two principal effects. It reduces the empty weight of the aeroplane, since the provision for supporting and securing inanimate shipments is of almost trifling weight when compared with the weight of the seating and sound-proofing and floor covering and ventilating arrangements, and the weight of the cabin attendants and of the food and water and provisions for dispensing them, that must accompany the carriage of passengers. Secondly, the expense of maintaining all these items and of selling passenger transportation and employing cabin attendants and of carrying insurance against misadventure to the passengers and a variety of other items is eliminated. In substituting goods for passengers it is typically possible to increase the payload by about a third, or even more if the aeroplane be initially designed exclusively for service with goods and the weight of windows be eliminated.

The items of cost that could be eliminated if no passengers were carried and no commercial traffic of any kind had to be solicited amount at present to about 7.5 cents per payload ton-mile. Upon the assumption that one-third of that amount would suffice to cover the cost of solicitation of freight traffic and the cost of loading freight and securing it in the aeroplane and handling it at the airports, the substitution of freight for passengers would allow a direct saving in cost of 5.0 cents per ton-mile. Superposing that saving on the reduction of unit cost due to the increase in the amount of payload carried, it appears that minimum operating costs per ton-mile can be reduced from the 18 cents that seem to represent the present limit with loads composed primarily of passengers to about 10 cents in the case of unmixed freight.

Of course the costs thus arrived at do not represent the possible levels of commercial charge. Although both British and American airlines are at present filling 90 per cent. of their available space, or better, they are doing it only through the machinery of priority systems, and with uncertainty and inconvenience to passengers and shippers which would seem unendurable in peace. The general experience, supported by a certain amount of mathematical analysis, seems to be that the maximum load factor that can be maintained without serious detriment to the value of the service to the public is from 65 to 70 per cent. The practically attainable load factor with cargo probably will not be very different from that with passengers, unless some sort of a deferred service is

introduced at rates substantially below the regular level to secure filler cargo. Either with passengers or with freight, then, the cost per ton-mile of service actually rendered may be expected to exceed the cost based on payload-capacity ton-miles by about 50 per cent. There is also the matter of profit, which may be expected normally to amount to about 10 per cent. of the operating expenses. The figures that I have previously discussed therefore build up to minimum practicable commercial rates on routes permitting frequent refuelling of about 3.0 cents per passenger-mile and 16 cents per ton-mile for air freight, with an additional charge in the latter instance if the cost of picking the package up from the shipper and delivering it directly to the final consignee is to be included. If a cruising speed of 250 m.p.h. at 10,000 ft. were to be insisted on, and the wing loading to be limited to 40 lb. per sq. ft., the passenger rate would have to rise to about 4.0 cents per passenger-mile.

If I apply to those figures my previously developed hope of a reduction of 15 per cent. in cost in the post-war period, beyond the best that can be done by merely choosing the best dimensions and design ratios for maximum economy in the present state of the art, I arrive at a possible post-war level of 2.5 cents per passenger-mile for passengers and 14 cents per ton-mile for goods.

The Volume of Cargo Traffic.

I have already drawn certain conclusions regarding the amount of passenger traffic that may be expected on typical routes after the war. Obviously the volume would depend on the rates of fare, but in my previous discussion of the subject I had in mind the probability of rates of the approximate order of 3.0 cents per mile in the United States, or the equivalent of about 1.6d. in Britain.

I have postponed the discussion of the probable volume of movement of goods, on the other hand, until I should have developed some specific predictions of cost from which to work.

Prior to the time when the war began to exert an important influence on the operation of the airlines of the United States, the total goods traffic on the airlines of the United States amounted, in ton-mile terms, to less than four per cent. of the passenger traffic. Goods traffic in Europe had been somewhat more highly developed, but with rare exceptions it still constituted a minor part of the total. I do not include mail in these figures, as the movement of mail by air is already much nearer to its saturation point than is the movement of passengers or cargo. The United Kingdom had been sending all letter mail over the Empire routes by air sometime before the war; and in the United States, notwithstanding the collection of postage at double the ordinary letter rate, approximately 15 per cent. of the total movement of non-local first-class mail within the continental limits was handled by air in 1942.

Goods traffic by air has been and will be at its best in cases in which the discovery of new natural resources or the development of new industrial enterprises creates a new demand for transportation into areas where no railways or good highways or waterway routes exist and where it would be difficult and costly to create them. There are such cases in some of the British dominions and in other parts of the earth, and the enormous movement of freight by air in northern Canada is one of the examples that proves the opportunities that such developments offer to air transportation, and the benefits that air transportation confers upon the communities in return; but surface transportation facilities are so highly developed in Europe and in the United States that instances of communities being exclusively dependent upon air transportation for their supplies, or finding air transportation more economical than the only available surface alternatives for all classes of freight, will be very rare in those areas. Even against the competition of the best surface transportation, however, lowered rates and the gradual habituation of industry to the advantages of the expeditious deliveries that air transportation permits will have a great effect.

If the transportation of goods from airport to airport, exclusive of collection and delivery services, can actually be offered after the war at rates approximating 14 to 16 cents per ton-mile in the United States, or tenpence per ton-mile in Britain, I believe that the movement of goods, instead of being a minute fraction of the volume of passenger traffic, will become a very large element in air transport operation. The actual magnitude of the cargo traffic developed will depend not only upon the direct balance of carrying charges against speed, but also on such accessory advantages of the aeroplane as the reduction of breaking and spoilage, the possibility of using simpler and lighter packing, and the elimination of the weight and cost of the shipment of perishable products on ice.

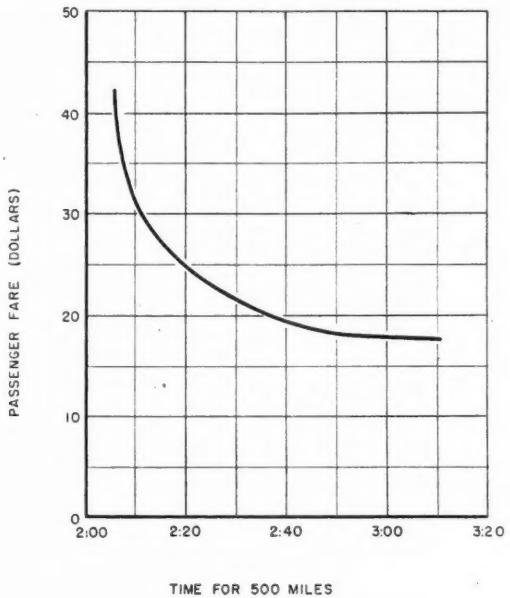


FIG. 11.

POST-WAR TRANSPORT SPEED.

Although it has for some years been generally recognised that exceptionally high speed in air transportation is incompatible with low cost, it remains pertinent to inquire into the rate at which the price having to be paid for speed accrues. Fig. 9 represents curves of minimum cost per payload ton-mile against cruising speed. The rapid increase of slope with increase of speed is conspicuous and characteristic.

The patron of air transport does not purchase speed in terms of miles per hour, but in terms of hours and minutes. In Fig. 11 I have constructed a curve of the estimated rate of fare for a 500-mile trip against the total time consumed in making such a trip against a 30-mile wind, including normal allowances for taxying, circling, climb, and descent. The curve is drawn to the assumptions that the product of wing loading and take-off power loading must not exceed 300, and that the wing loading must not exceed 45 lb. per square foot.

It is obvious that as the inter-city time is decreased, a mounting price has to be paid for each succeeding minute saved. In Fig. 12, the additional charge to the passenger per unit of time saved is plotted against speed. The form of that curve, and the values of its ordinates, are but little affected by the length of flight.

It appears that the charge that would have to be made for carrying a passenger over a 500-mile distance in 2 hours and 7 minutes, to keep an airline self-supporting, would be more than twice as great as the charge for covering the same distance in three hours; and that the rate of fare for the three-hour journey would have to be increased by 30 per cent. for the first 33 minutes of time saved; a like amount for the next 12 minutes; and by as much more for the next six.

Presumably there is some limit to the amount that the average passenger, or for that matter the average user of mail or freight service, is willing to pay for the saving of time. Although there will always be isolated instances in which it would be worth almost any amount to secure the quickest possible transportation, they are likely to be too few to supply the basis for a regular transport service. It is a matter on which everyone can form his own opinion; but I suggest it as my own belief that only a very limited number of passengers would be willing to pay at the rate of more than $10.00 per hour. To make that conclusion a valid one, it would be necessary to suppose that if there were two services between New York and Chicago, one making the trip in an average of 4.5 hours and with an average fare of $40.00, approximately as at present, and the other doing it in 2.5 hours at $60.00 fare, they would be reasonably equal in their attraction to the travelling public.

The curve in Fig. 12 indicates that the cruising speed at 10,000 ft. could be pushed up to 235 m.p.h. before reaching the point where additional increments of speed would increase the cost to the passenger at a rate of more than $10.00 per hour saved.

From the charts that have been presented it is possible to construct an image of the aircraft from which it would be reasonable to expect this performance. It would be an aeroplane capable of carrying 40 passengers with their ordinary hand baggage and 4,000 lb. of mail and cargo. It would have a wing loading of approximately 34 lb. per sq. ft. and a take-off power loading of 9 lb. per horsepower. Its gross weight at take-off would be approximately 62,000 lb.; the wing area 1,800 sq. ft.; and the four engines would have a take-off rating of 1,700 h.p. each. The total operating costs should be about $1.45 per mile.

If the rather stringent take-off stipulation that underlay the plotting of Figs. 11 and 12 were relaxed, and the wing loading allowed to increase to 45 lb. per square foot, the same speed should be attained with the same payload in an aeroplane of about 53,000 lb. gross weight, with four 1,400 h.p. engines, and with the operating cost reduced to $1.35 per mile. The effect of abandoning the take-off limitation entirely, allowing the product of wing loading and power loading to run up to indefinitely high values, would be to increase the maximum economically justifiable speed, on the assumptions adopted herein, by only about ten miles an hour.

In Fig. 13 I have plotted the maximum speed compatible with reasonable economy, as just determined, against size of the aircraft in terms of passenger capacity, assuming that passengers will constitute two-thirds of the payload. The figure set at 235 m.p.h. for a machine of about 40-passenger capacity would appear to drop to a maximum economical speed of only 215 m.p.h. for a 20-passenger aircraft and rise to 255 m.p.h. for one designed to carry a hundred passengers.

This is the third occasion on which I have examined the general question of determination of maximum economical speed.[6] It is, of course, possible to take many variables into account in such an analysis now for which we had no adequate experience a decade ago; but the methods of the three studies were sufficiently similar to permit a comparison of their results. In 1929 the maximum cruising speed that could be attained without running into costs in excess of

[6] "The Economic Speed-Weight Relation in Air Transportations," S.A.E. Journal, December, 1929, pp. 635-640. "Economic Factors and the Evolution of Air Transport Design," a paper presented to the Institute of the Aeronautical Sciences in January, 1940.

INCREASE OF FARE (DOLLARS) PER PASSENGER-HOUR SAVED BY FURTHER INCREASE OF SPEED

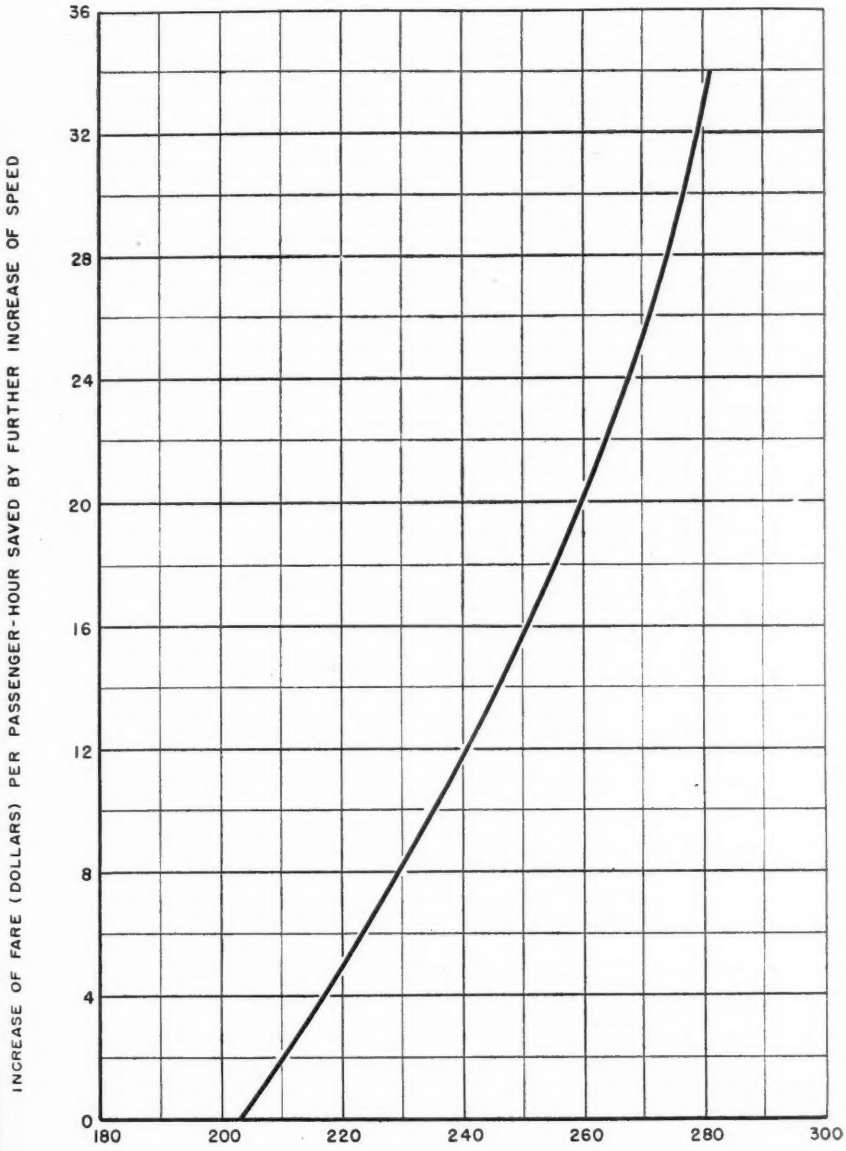

INCREASE OF FARE (DOLLARS) PER PASSENGER-HOUR SAVED BY FURTHER INCREASE OF SPEED
36
32
28
24
20
16
12
8
4
0
180
200
220
240
260
280
300
CRUISING SPEED AT 10,000 FEET (M.P.H.)

FIG. 12.

$10.00 per hour for the saving of time appeared to be about 130 m.p.h. for a 12-passenger aeroplane. In 1940 the corresponding figure was a little over 190 m.p.h. for a machine of 20-passenger capacity. Looking forward now to the post-war period, and making appropriate corrections to eliminate the direct effect of size of aircraft on speed, the maximum economical speed in air transportation at moderate altitude appears to be about 75 m.p.h. higher than in 1929 and 25 m.p.h. higher than it was in the state of the art that prevailed three years ago. The gain is due in part to a general improvement in efficiency, and especially to reduction of drag—in part to increase of wing loading—and in part to the fact that the development of operating practices over the past dozen years has increased the relative importance of the items of cost that decrease in importance with increase of speed, while reducing the relative significance of those that increase with increase of power.

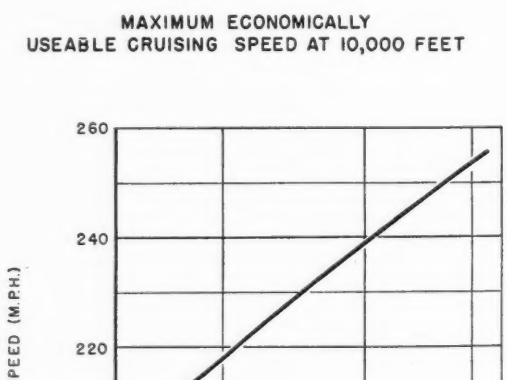


FIG. 13.

Any increase in the amount of equipment that must be carried in all transport aircraft will tend to reduce the economically usable speed. If the navigational methods of the future require a substantial increase in weight of the radio equipment carried, for example, or if there is a substantial increase of weight on account of complete de-icing provision, the adverse effect on payload will be relatively greater at high speed than at low, and the economic burden of high-speed operation will be increased thereby. Increases in weight of this sort also have the effect, of course, of improving the relative position of large aircraft.

Fig. 13 revives the question of whether it is better to run small aircraft very frequently or large ones at longer intervals. Upon the hypothesis on which the curve of economical speed against size is drawn, the block-to-block time of a 100-passenger aircraft over a 500-mile distance ought to be some 20 minutes less

than that of a 20-passenger machine. Even if no passengers were being carried for intermediate points, it seems probable that greater satisfaction would be given to the average passenger, at least over such short distances as 500 or 1,000 miles, by the closely spaced departures that the small aircraft would permit than by the saving of some 15 per cent. in time that could be made by using a very large aircraft. That would, of course, be subject to modification in cases where the traffic is heavy enough to allow high frequency of departure even with a machine approaching 100-passenger capacity—although routes meeting that specification are likely to be rare.

There is, of course, a possibility of going still further. Upon the assumption that stability and control difficulties can be overcome in a true flying wing, and that the percentage of total structural weight in such a machine of very large size can be kept reasonably close to the figures characteristic of smaller transport aircraft, a 400,000-lb. aeroplane with a capacity for 350 passengers might be expected to have a maximum economically usable cruising speed at a height of 10,000 ft., in flights of moderate length, of some 280-300 m.p.h. Such an aircraft might have unit costs 20 per cent. lower than those of a 40-passenger transport, and an inter-city time from 15 to 20 per cent. less than would be economically practicable with the 40-passenger aircraft. To secure the actual benefit of the lower operating cost, however, it would be necessary to maintain as high a commercial load factor in the large aircraft as in the small one; and that would be difficult in view of the diminishing flexibility of service as the size of the individual aircraft is increased, and the consequent tendency for average load factors to fall. If the future development of aircraft design reveals no serious aerodynamic shortcomings in the flying wing, and if the natural tendency to increase of structural weight with increase of size can be offset by ideal weight distribution, there would be a place for such an aircraft on a transatlantic route. Its aerodynamic and economic advantages would be secured at the expense of being able to schedule only one round trip each day, or possibly only three or four a week in winter, in place of the frequency of four or five trips a day that has previously been suggested as really satisfying the travellers' convenience. There are also a few other routes in the world, such as that between the Atlantic and Pacific coasts in the United States, on which one or two schedules a day with an aircraft of such size might be justified, especially if the available passenger and mail loads are supplemented by large amounts of cargo—but the opposing claims of the advantages of high frequency will be constant and insistent.

All these conclusions have been drawn with reference to passenger traffic. Upon the same basis on which I concluded that $10.00 per hour represents a reasonable valuation of the saving of time for the average passenger, I believe that only for very exceptional cargo would the value to the shipper of time saved exceed two cents per hour per pound of weight, or the equivalent of $4.00 for the weight of a passenger. If that be right, the maximum economically usable speed with cargo alone would appear to be about 20 m.p.h. lower than with passengers.

Effect of Altitude.

The discussion up to this point has related only to operations at an altitude at which passengers can be safe and comfortable without oxygen or cabin-supercharging. Now the effect of raising the operating altitude has to be examined.

Certain of the inherent advantages of supercharged cabin operations, in the elimination of passenger discomfort and in making it possible to go above a substantial proportion of the storm and icing conditions, are obvious. Supercharging also has the merit of making it possible to descend through the overcast at any desired rate, without having to consider the effect of rapid pressure change on the passengers; and it may thereby simplify the problems of traffic

control. For some routes the supercharged cabin will not only be helpful but indispensable; but in considering whether it is a feature to be accepted only when necessity dictates, or one to be eagerly espoused in every instance, its effect on economy must be considered.

As in the problems previously discussed, the major economic effects occur through variations in the proportion of payload that can be carried. I have made no attempt at a close analysis of the direct effect of supercharging on operating

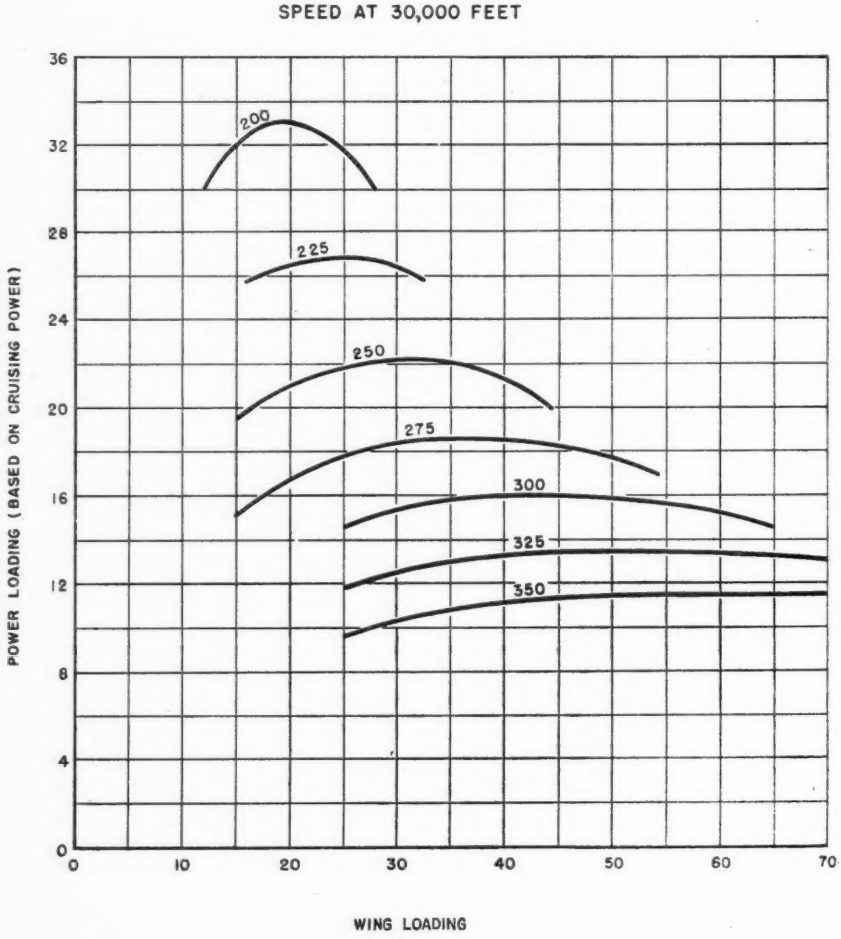


FIG. 14.

cost, through the increase of depreciation and of maintenance expense; but in round numbers those items will probably increase the total cost by about five per cent. For the purposes of the following studies I have assumed—perhaps rather optimistically—that within a short time after the end of the war commercially satisfactory power-plants will be available to produce enough power for cruising and a reasonable rate of climb up to an altitude of 30,000 ft. with a gear-

driven blower. I have assumed that it will be possible to provide cabin supercharging for a total expenditure of weight in the cabin blowers, in the valves and controls, and in the fuselage structure of 3·5 per cent. of the gross weight of the aircraft, and that the increase of weight in the engines and propellers for high altitude operation will be 0.2 lb. per take-off horsepower. I believe that those figures represent reasonable probabilities.

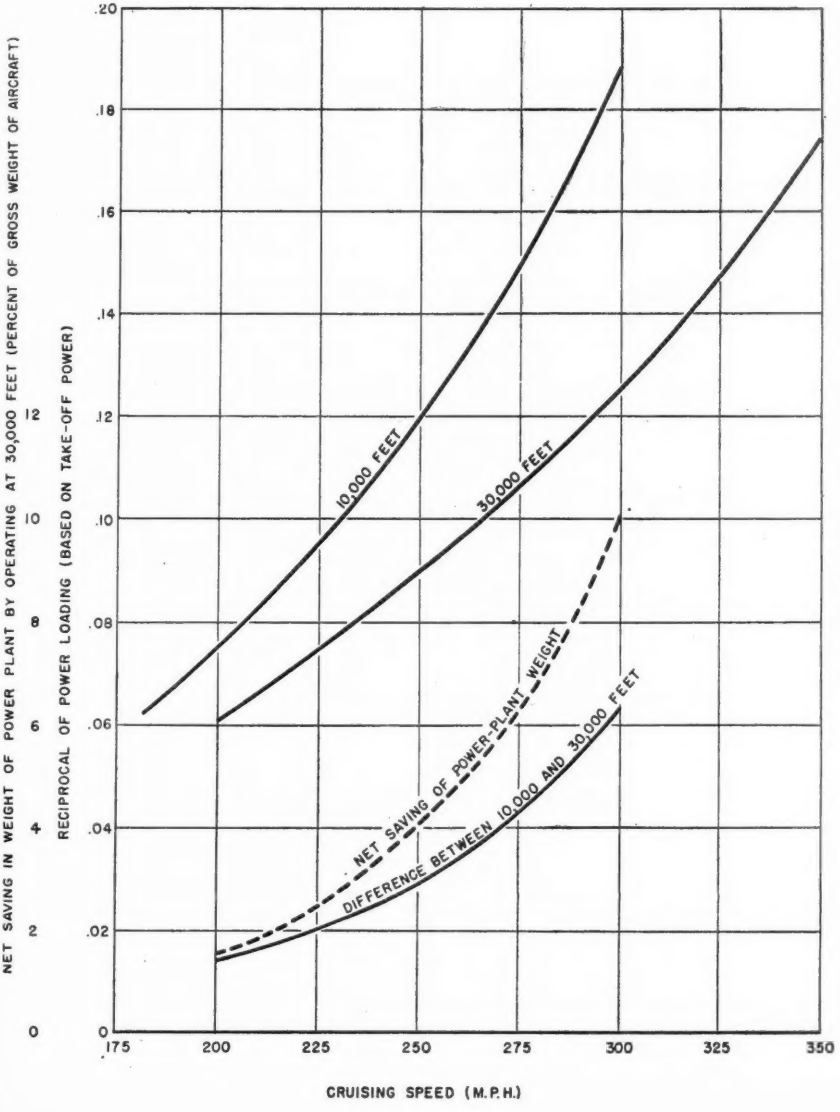


FIG. 15.

Fig. 14, computed in the same fashion as Fig. 5 and upon the same assumptions in every respect except as to altitude, shows the cruising speed at 30,000 ft. as a function of wing loading and power loading. The optimum wing loading if speed alone be considered is, of course, but little more than half the optimum for 10,000 ft., and closely approximates $5(V/100)^2$.

In Fig. 15 the take-off horsepower required per pound of gross weight is plotted against cruising speed for the two altitudes, assuming that in every case the optimum wing loading will be used up to, but not in excess of, 50 lb. per square foot. A third curve gives the difference of the power-weight ratios, or the variation with speed of the amount of power per pound of gross weight that would be saved by flying at 30,000 ft. instead of 10,000. The last curve shows the total effect of high-altitude operation on power-plant weight, allowing for a basic power-plant weight of 2.0 lb. per horsepower and for increase of weight for supercharging as previously assumed.

If only uniform operation at cruising speed had to be considered, the saving in power-plant weight by high-altitude operation should be sufficient to balance the additional weight of cabin supercharging provision at all speeds above 240 m.p.h. There are, however, certain additional factors to be taken into account:—

(*a*) Saving of fuel weight by high-altitude operation (assuming a uniform speed);

(*b*) Increase of structural weight due to lighter wing loadings for high altitudes;

(*c*) The effect on block-to-block speed of the time lost in climbing to high altitudes.

The first point is in favour of high-altitude operation; the second and third are against it.

The increase in structural weight due to increase in wing area amounts to little at high speeds, since the wing loading in that case is likely to be limited by considerations of take-off and landing to such values that the operating altitude will make but little difference in the loading used. If operation at moderate speeds is planned, however, the wing loading for a high-altitude aircraft must be kept low in order that the cruising altitude may not be unduly near the stall. The weight penalty of added wing area has then to be paid. I have estimated that its amount, for an increase of cruising altitude from 10,000 ft. to 30,000 ft., will vary from zero at a speed of 275 m.p.h. or more to four per cent. of the gross weight at 200 m.p.h.

Assuming the climb to be made at not over 75 per cent. of take-off power, the net loss of time in climbing from 10,000 to 30,000 ft., as compared with the time required for covering the same distance in steady cruising at 30,000 ft. and at the same power output, is assumed to range from 10 minutes at 300 m.p.h. to 15 minutes at 200. For equal average speed made good from take-off to landing, the cruising speed of the high-altitude aircraft must therefore exceed that of the medium-altitude machine by a little more than 10 per cent. if a comparison is being made for a 500-mile flight, and by an amount inversely proportional to the distance for longer distances.

On those assumptions, and with proper allowance for the effect of power loading and speed on fuel consumption, the apparent difference between the payload in operating at 30,000 ft. and that in operating at 10,000 ft. is plotted against speed, for several lengths of flight, in Fig. 16.

The speed above which the use of cabin supercharging promises to effect an actual economy of weight decreases with increase of distance from approximately 280 m.p.h. for a 500-mile flight to about 200 for one of transatlantic length.

The gain by high-altitude operation at very high speeds and over very long distances is impressive; but unfortunately the combination of high speed and long distance remains an uneconomical one, whatever the altitude may be. The maximum economically usable speed as previously discussed herein

INCREASE OF PAY-LOAD BY HIGH-ALTITUDE OPERATION (IN PERCENT OF GROSS WEIGHT)

must be expected to decrease with increasing length of non-stop flight; and it seems probable that in the present state of the art it will decrease rapidly enough to remain persistently below the speeds at which high-altitude operations begin to yield a net benefit in payload.

For flights of extreme length, for which the greatest possible economy of fuel is paramount, the total consumption of fuel in high-altitude operation may

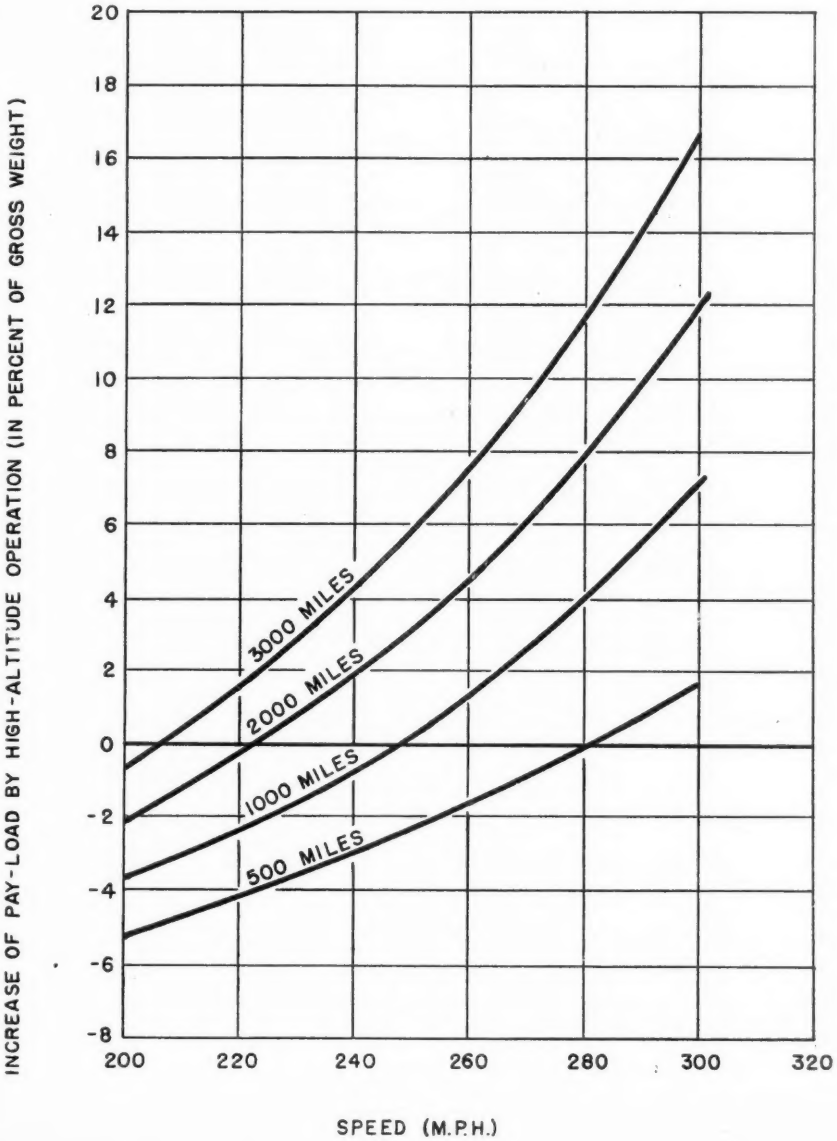


FIG. 16.

be expected, if changes of wind at altitude be neglected, to be very nearly the same as at medium altitudes. The high-altitude operation in that case has the disadvantage of requiring somewhat higher power for maximum-range operation than would have to be drawn from the engines of a medium-altitude aircraft; and has the further initial handicap of bearing the weight of the supercharging equipment. On the other hand its speed for maximum endurance will be higher than that of its medium-altitude competitor. It is therefore in a better position to combat unfavourable winds, provided that they, too, do not increase rapidly in velocity with increase in altitude.

In summary, it would appear that if a high degree of economy is desired in a transport operation supercharging will be used only when weather conditions along the route are such that high-altitude operation will contribute notably to safety and regularity of service. If on the other hand it is not a primary objective to keep costs close to the lowest possible level, the operating advantages and the luxury of supercharging can be secured at the expense of a total increase of cost per payload ton-mile of 10 or 15 per cent. in the range of most probable operating speed. In the still more extreme case of determination to attain very high speed at almost any cost, high-altitude operation is a part of the specification for keeping the expense of the speed to a minimum.

Long-Range Operations.

Non-stop flights of more than ordinary length fall into two categories. The non-stop distance may be imposed by the lack of possible intermediate fueling facilities, particularly on over-water flights; or it may be freely chosen, in the interest of greater speed, economy, convenience, or passenger comfort. In the first instance, the operating conditions and the design of the aircraft must be adjusted to fit the required range, so that a reasonable approach to maximum economy may be attained. In the second instance the burdens imposed by long-range operation must be analysed to determine the point at which it will become advisable, in the interest of economy, to forego the advantages of non-stop flight in the interest of attaining an increase of payload.

The insertion of an intermediate stop not required for traffic reasons involves loss of time, and in many cases a sacrifice of regularity of operation. The loss of time in landing, refuelling, and taking off and climbing back to cruising altitude is direct and reasonably predictable. The loss of regularity is less determinate. It depends upon weather conditions at the proposed intermediate points and upon the amount of progress that is to be made in continuing operations in spite of weather difficulties. One extreme instance is familiar to all of us. Under present conditions, trans-Atlantic operations depending on Newfoundland as an intermediate stop would suffer many cancellations and delays which would be avoided in a non-stop operation between the United Kingdom and the United States or the Canadian mainland. The use of the Azores as a refuelling point for seaplanes presents similar difficulties, due in that instance to water conditions rather than to weather. There are, on the other hand, many cases in which the climatic conditions at the potential intermediate stops are good enough so that no appreciable proportion of cancellations need be feared as the result of their use. In those instances the decision can be based on considerations of overall speed, economy, and operating convenience.

Fig. 17 provides some of the data for a decision in such a case. For an assumed 5,000-mile flight in still air, and for block-to-block speeds of 160, 200, and 240 m.p.h. respectively, the cruising speed required to make good the desired overall speed is plotted against the length of the individual flight stage. Operation at an altitude of 10,000 ft. is assumed, and the length of time actually spent on the ground at each stop is taken as varying from 10 minutes to refuel after a 500-mile flight to 30 minutes for refuelling after one of 2,500 miles.

The curves of required cruising speed are relatively flat as long as the length of the individual stage is at least 1,000 miles. For stops spaced more closely than that the required cruising speed rises more and more sharply, until for the 400-mile distance it has to exceed the block-to-block speed by about 20 per cent. and for a 200-mile distance about 50 per cent. The differences between block-to-block speed and cruising speed, for a given length of flight, of course increase both absolutely and relatively with increase of speed.

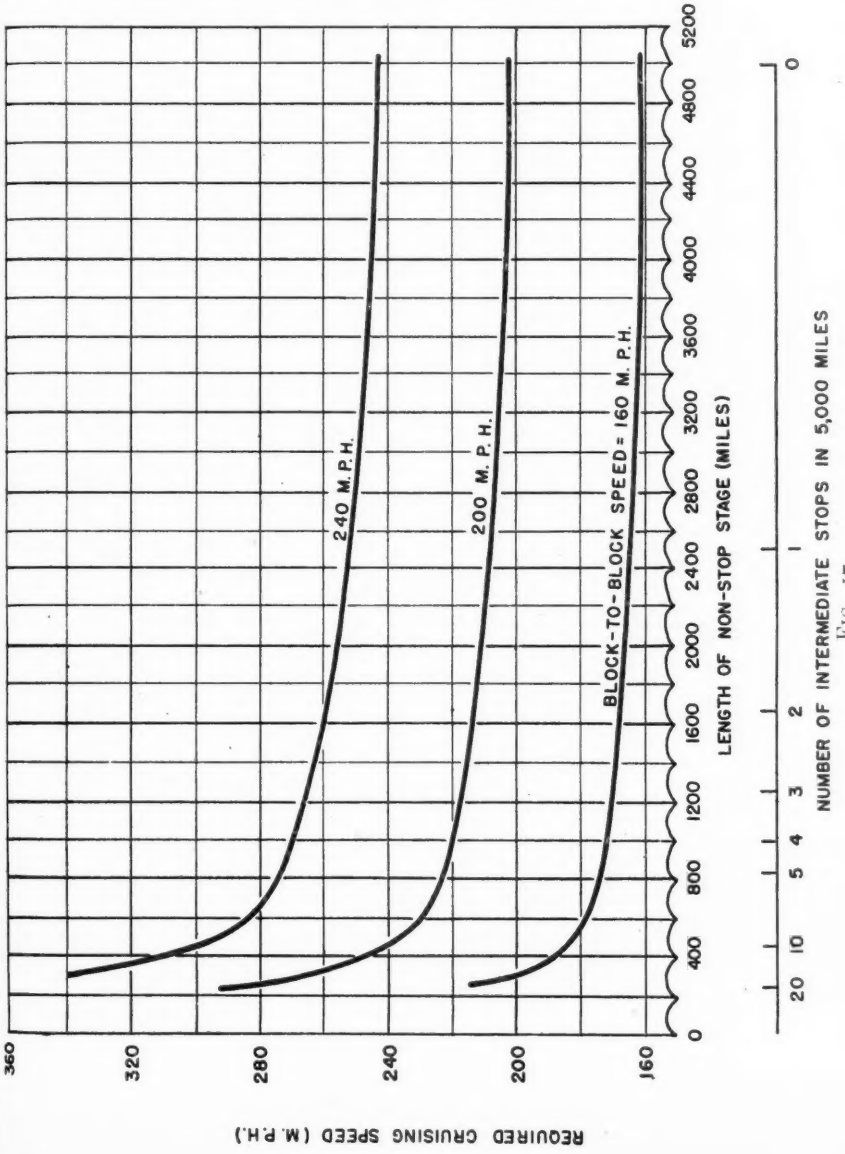


FIG. 17.

In Fig. 18 the study has been extended, for the particular case of a block-to-block speed of 200 m.p.h. over a 5,000-mile distance, to an analysis of the variation of payload with frequency of stops. The major factors controlling payload under these conditions are:—

(*a*) Increase of fuel load required as the length of stage is increased.

(*b*) Increase of power-plant weight and structural weight with increase of cruising speed, as required over the shorter distances to make good the desired block-to-block speed.

This analysis, like most of those that have preceded it, is based on a four-engine aeroplane of about 60,000 lb. gross weight and upon the best aerodynamic and structural characteristics that seem reasonably sure to be attainable in transport aircraft built immediately after the war.

Specific fuel consumption is assumed at 0.42 lb. per h.p.-hr. Take-off power is assumed to be governed by the two requirements that the average cruising power used throughout the flight must not exceed 50 per cent. of take-off power, and that the cruising power in the initial stage, with the aircraft in its most heavily loaded condition, must not exceed 65 per cent. of take-off power. An aircraft which meets the latter requirement will normally have a rate of climb of at least 500 ft. per minute on take-off power, and ability to accomplish the take-off should therefore present no problem. Some empty weight might be saved by using a higher take-off power loading, but it would be at the expense of having to increase the proportion of take-off power used in cruising to such an extent that a considerable increase in specific fuel consumption in the early portion of flight would result. The requirement as here set forth is roughly equivalent to a maximum limit of 32 for the product of take-off power loading and the square root of the span loading at take-off. For an aspect ratio of 12, the product of the take-off power loading and the square root of the wing loading at take-off would be limited to 110.

The fuel carried is computed on an assumption of flight against a 40-mile wind, together with an allowance for increase of distance, due to detours or navigational errors or having to proceed to an alternative destination, of from 250 miles for the shortest distances to 500 for the longest, and an additional fixed reserve for approximately one hour of cruising operation. The combined effect of these several factors is to call for a fuel supply which exceeds the amount required to cover the designated non-stop distance at cruising speed in still air by a proportion ranging from 55 per cent. for a 5,000-mile distance to 175 per cent. when the distance is 300 miles. Fig. 18 also includes a curve of fuel load, and one of the power loading required at take-off in order that the specified block-to-block speed may be attained.

To allow for accommodation adequate for a long flight, whether it be made in a single stage or several stages, the total weight of all those items which can be considered as directly proportional to passenger load has been taken to be equal to 50 per cent. of the payload. It is assumed that where intermediate stops are made, changes of crew will be possible; and the size of the operating crew carried in flight is therefore assumed to increase progressively with distance from a crew of three for non-stop distances of 720 miles or less to one of nine for a 5,000-mile flight.

Under these conditions, the maximum payload at a given block-to-block speed would be carried by dividing the flight into stages of approximately 500-mile length. In view of the inconvenience of making any unnecessary stops and expense of maintaining the ground personnel at an increased number of points, the practically desirable distance between stops where economy is a factor of major importance would appear to range from 700 to 1,250 miles. For non-stop distances greater than 1,250 miles the economic penalty accumulates rapidly.

These conclusions may be over-conservative. The assumptions regarding fuel reserves, in particular, are generous; but I have assumed that regularity of

PAYLOAD FOR AVERAGE BLOCK-TO-BLOCK SPEED OF 200 M.P.H. OVER 5,000-MILE DISTANCE

service will be regarded as of such importance that fuel loads will be kept large enough so that the postponement of trips to allow exceptionally strong headwinds to pass will be a very rare event. Certainly on some routes weather conditions will be stable enough to permit the use of smaller reserves than I have assumed. If such favourable conditions made it possible to reduce all fuel reserves to half the amount assumed in constructing Fig. 18, the slope of the righthand part

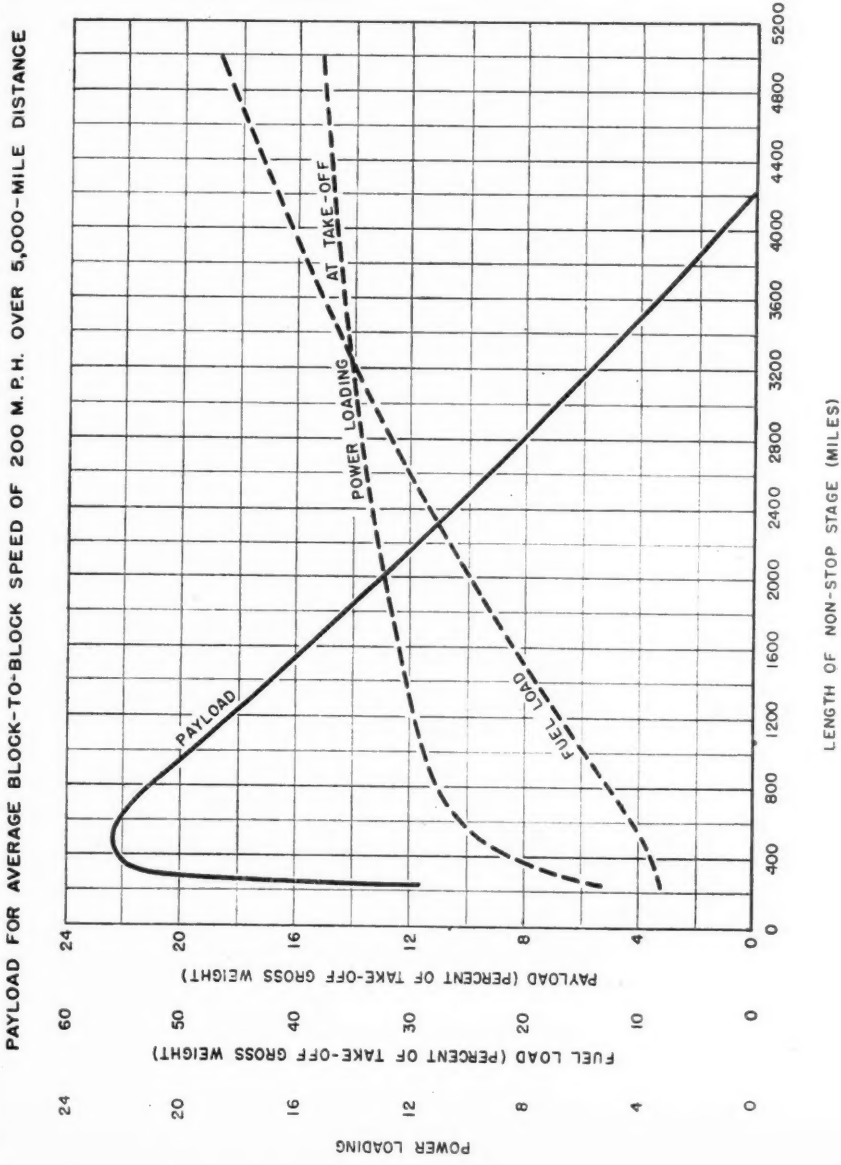

PAYLOAD FOR AVERAGE BLOCK-TO-BLOCK SPEED OF 200 M.P.H. OVER 5,000-MILE DISTANCE
PAYLOAD
POWER LOADING AT TAKE-OFF
FUEL LOAD
LENGTH OF NON-STOP STAGE (MILES)
0 400 800 1200 1600 2000 2400 2800 3200 3600 4000 4400 4800 5200
PAYLOAD (PERCENT OF TAKE-OFF GROSS WEIGHT)
0 4 8 12 16 20 24
FUEL LOAD (PERCENT OF TAKE-OFF GROSS WEIGHT)
0 10 20 30 40 50 60
POWER LOADING
0 4 8 12 16 20 24

FIG. 18.

of the payload curve would be reduced by about a third. The proportion of payload over a 2,500-mile distance, for example, would be increased from 10 per cent. of the take-off gross load to about 13.5.

I have not attempted as extended an analysis of costs in long-range operations as I made for the 500-mile distance; but variations of payload are even more the controlling factor in long-range operations than in short-range, and some approximations can easily be made. For the case plotted in Fig. 18 the total operating cost per ton-mile, assuming that the load is composed in large part of passengers and that the customary passenger service costs have therefore to be included, would appear likely to be about:—

Length of flight stage.	Estimated total operating cost per ton-mile (cents).	British equivalent.
600	22	1/3
1,000	24	1/4
1,500	26	1/6
2,000	30	1/8
2,500	36	2/0
3,000	47	2/8
3,500	75	4/2

Under these particular conditions, the interpolation of a Newfoundland stop in a London-New York flight ought to bring the passenger fare to a figure about 50 per cent. below that required for non-stop flight, provided that the handicaps of Newfoundland weather can be so far overcome as to permit a reasonably regular operation.

Larger payloads can be carried over long distances, and better economy thereby attained, if somewhat lower speeds are accepted. The most economical speed at an altitude of 10,000 ft. is typically somewhat less than 30 times the square root of the wing loading; and unless wing loadings are to be increased to well outside the range of values that has heretofore been seriously considered in connection with air transport, the most economical mean speed during a long flight at moderate altitude is likely to remain below 180 m.p.h. While economical speed can be increased by increase of wing loading, it is at the expense of an increase in drag coefficient and therefore in fuel consumption. Fig. 19 shows the variation in fuel consumption with speed for three different wing loadings and two different distances, always upon the assumption of the best state of the designer's art that is immediately foreseeable. The values as plotted include customary reserves for deviations from course and consumption during climb, but assume that the worst predicted wind condition will be that of still air. The wing loadings referred to in Fig. 19 are mean wing loadings during the course of the flight—the corresponding loading at take-off being appreciably higher, and that at landing correspondingly lower. In the next chart (Fig. 19*a*), curves are given for variation of consumption with speed over the same distances and for three different conditions, the wing loading at each speed being assumed to be that corresponding to minimum consumption.

In still air the theoretical minimum consumption would be attained with a very low wing loading and speed. In the much more practical case of having to anticipate a 40-mile headwind the most economical air speed is plotted for 160 m.p.h.; while for an 80-mile wind it increases to 190 m.p.h. For a head-wind of 120 m.p.h., the most economical air speed would be about 230 m.p.h.

Fig. 18 has indicated a maximum probable payload of 10 per cent. of the take-off gross load for a 60,000 lb. aeroplane making a block-to-block speed of 200 m.p.h. in a 2,500-mile flight, on the assumption that the fuel load is such as to make it possible to complete the flight against a steady 40-mile wind. The reduction of block-to-block speed from 200 m.p.h. to 160, with the conditions

otherwise unchanged, would reduce the fuel consumption by 2.0 per cent. of the take-off load; it should reduce the empty weight of the aeroplane by about 2.5 per cent. of the take-off load, due principally to the higher power loading which the reduced cruising speed would make possible; and the payload would be increased correspondingly. I do not by any means suggest that post-war cruising speeds in long-range transport operations are actually to be conducted

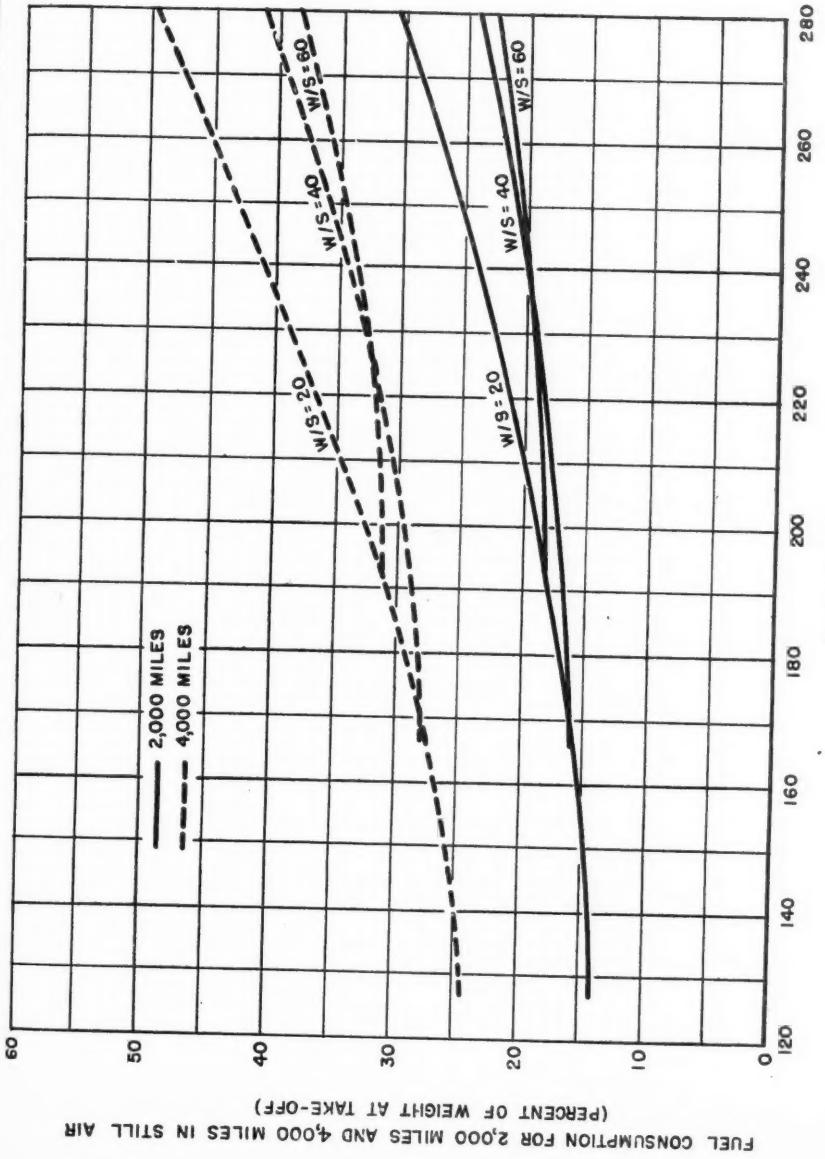


FIG. 19.

in the range of 160-180 m.p.h.; but it appears that a certain price will have to be paid for operating at speeds much above that level, and that as the speed increases the price becomes more and more substantial.

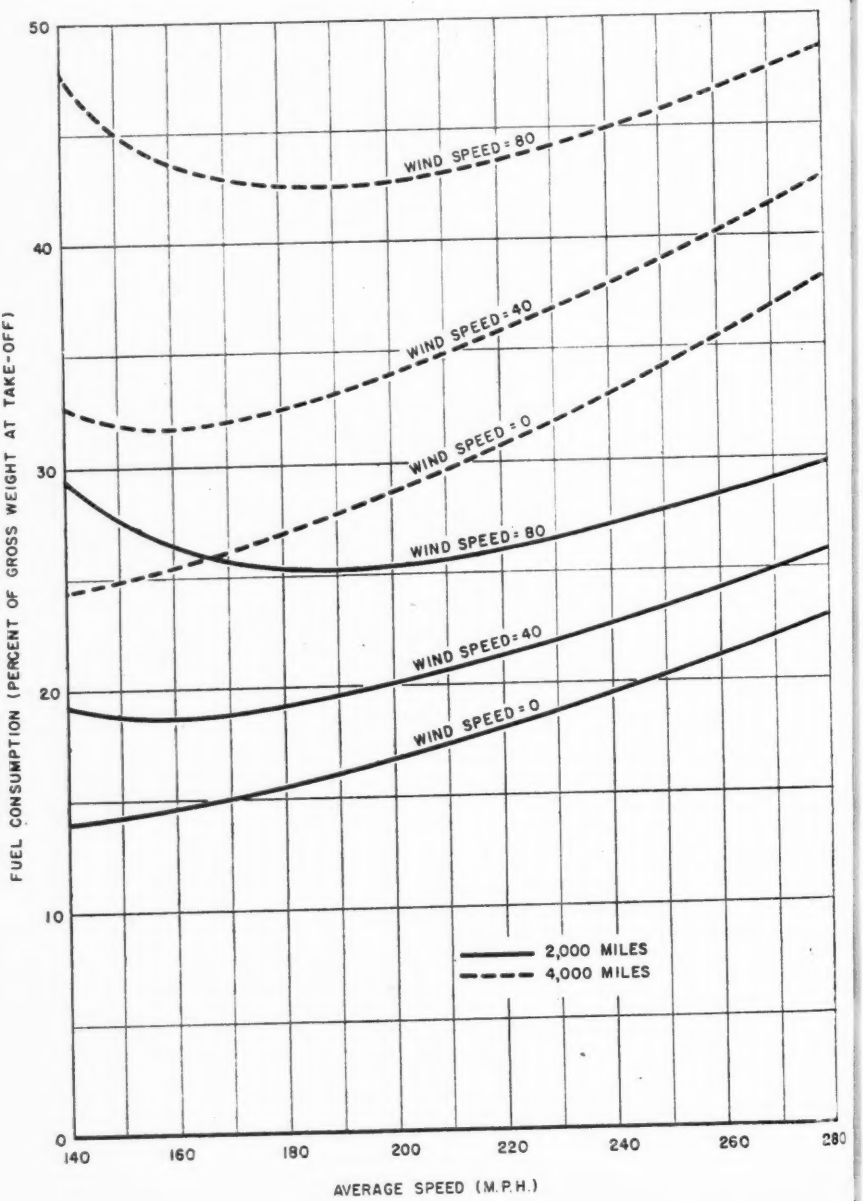


FIG. 19a.

The factor of aeroplane size remains to be considered. Two assumptions are common in present discussions of the future of very large aircraft. It is assumed that they will have notably lower drag coefficients than will be possible for aircraft of smaller size; and that, in order that the proportion of gross weight having to be devoted to structure may be restrained from increasing, they will

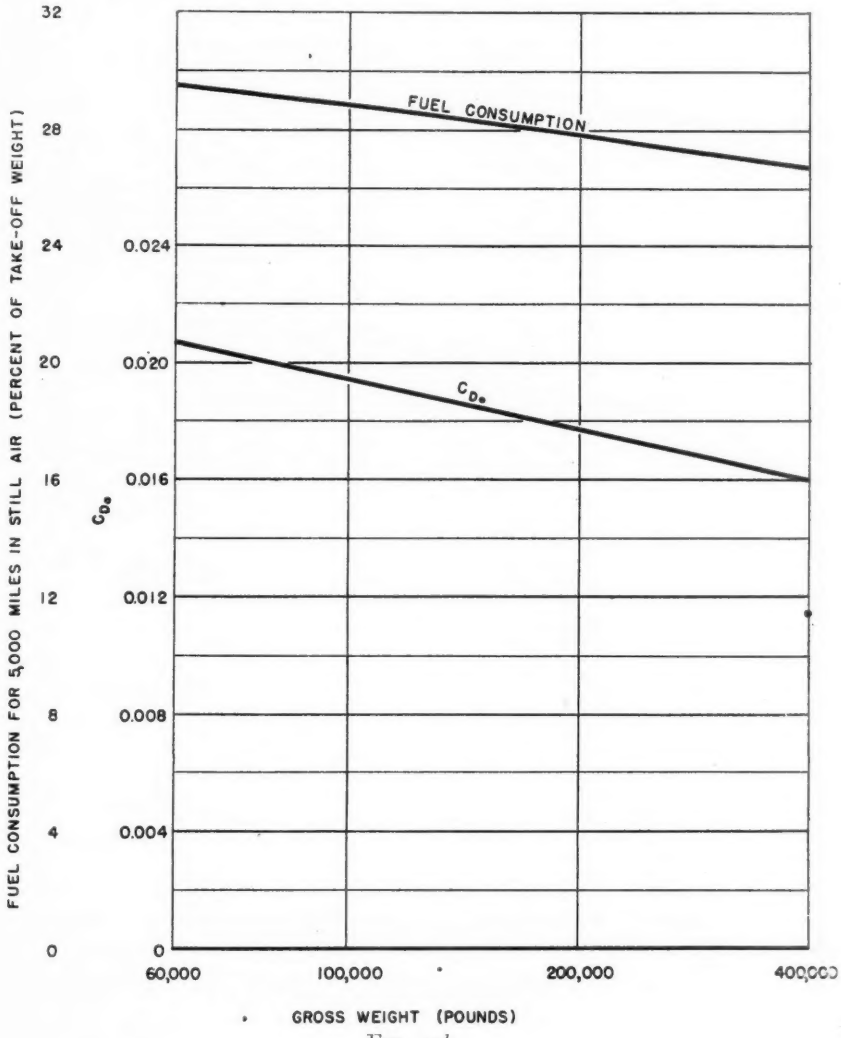


FIG. 19*b*.

require very high wing loadings. Unfortunately these two prospects are in some degree contradictory, since the increase of wing loading increases the minimum D/L, and thereby offsets, at least in part, the inherent virtues of large size in reducing fuel consumption. I have not attempted any extended analysis of the

variation of structural weight with size, on which experience with very large aircraft is so far limited and somewhat conflicting; but I have used the assumptions introduced in an earlier section of the lecture with regard to the variation with size of the drag of individual parts of the aircraft; I have superposed them on an assumed gradual increase of mean wing loading (average of loadings at take-off and at landing) from 40 lb. per sq. ft. in the 60,000 lb. aircraft to 60 lb.

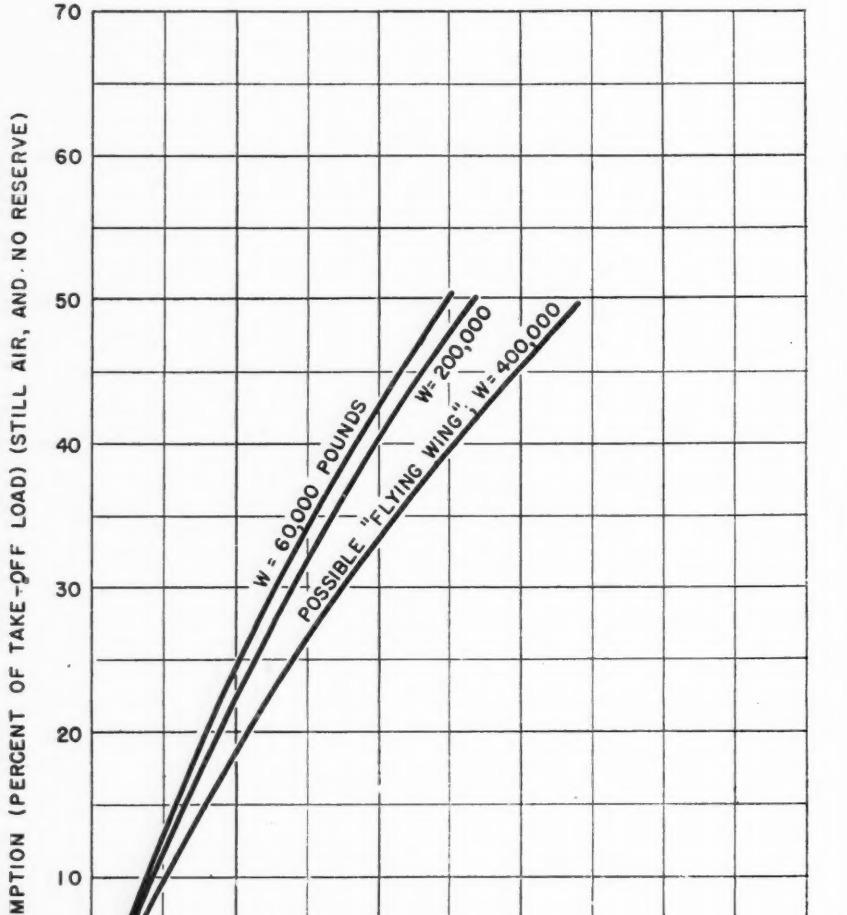


FIG. 19c

per sq. ft. at 400,000 lb.; and I have plotted in Fig. 19*b* the corresponding variation of drag coefficient and of fuel consumption in a 5,000-mile flight in still air (roughly equivalent to a 3,000-3,800-mile commercial operation, the exact figure of equivalence depending upon prevailing winds, availability of emergency landing places short of the assigned destination, and other factors).

On the particular assumptions adopted here, the decrease of relative fuel consumption with increase of size is disappointingly slow. An increase of gross weight from 60,000 lb. to 200,000 lb., for example, would decrease the relative consumption over a 5,000-mile distance in still air by only about 1.7 per cent. of the initial gross weight. The large aircraft would have a further advantage in that its economical speed would be somewhat higher and the relative effect of a given headwind therefore less. It would also score a point in that the greater accessibility of the power plants during flight and the possibility of carrying more engineering personnel and specialised power-plant instruments should permit the attainment of a lowered specific consumption; but the changes in fuel consumption with size would still appear likely to be so small that variations of the ratio of empty weight to gross will be the primarily controlling factor in determining the economically advantageous size for long-range operation.

The optimum distance between refuelling stops, in cases where the operator has some freedom of decision in that respect, tends to increase with increase of size of the aircraft. The lower fuel consumption of the larger aircraft decreases the penalty attached to operations over relatively long distances; but it is even more important that the length of time lost in manœuvring a very large machine for a landing and in refuelling it at an intermediate stop is almost sure to be greater than with aircraft of smaller size, and larger sacrifices in payload may therefore be acceptable in the interest of eliminating stops. I have suggested that the best practical distance between refuelling stops, in cases where their location is not controlled by considerations of traffic and where a given block-to-block speed is required to be maintained over the total length of the route, would be from 700 to 1,200 miles for a 60,000 lb. aircraft. For a machine of 200,000 lb. weight those distances might be increased, by the practical considerations just referred to, by from a third to a half.

As a final look into possible future development on this point, I have returned to the true flying wing of 400,000 lb. weight. For such a machine the fuel consumption in a long flight ought to be about 15 per cent. lower than in the conventional aeroplane of the same weight as plotted in Fig. 19*b*.

In Fig. 19*c* fuel consumption, again as a fraction of gross weight at take-off, is plotted against length of flight for the three cases of the 60,000 lb. aeroplane that seems realisable in the very near future; of the 200,000 lb. aeroplane similarly realisable; and of the hypothetical flying wing of 400,000 lb. gross weight. These curves represent cruising consumption only, with no allowance for headwinds, no reserves, and no allowance for power used in take-off and climb. In giving them any practical application, they must be adjusted accordingly.

Regulation of Airworthiness Requirements and Air Transport Operation.

No one who has to deal with problems of regulation, either of airworthiness or of the conditions of aircraft operation, can fail to be deeply sensible of his responsibility. Mistaken regulation can put a drag on development, or it can warp it into unsound and unprofitable directions. The United Kingdom has entrusted the formulation and application of airworthiness regulation to a semi-public body, of which most of the members are chosen from the industry. In the United States the responsibility remains with an agency of Government; but we both have the same problems. On the one hand we are constrained by the desire to include margins of safety that will leave no possibility of avoidable hazard—on the other, by the desire to impose no burdens on operation, and no economic handicaps on aircraft design, which do not genuinely correspond to the

interest of safety. The processes of regulation tend to grow more and more elaborate as aeronautical science and the art of aircraft design accumulate new refinements. It grows progressively more difficult, yet at the same time progressively more important, to keep regulation abreast of technical development, so that there may be no regulatory time-lag in the practical application of the products of research and invention.

In Dr. Roxbee Cox's Wilbur Wright Lecture of three years ago he said, among many other wise and thought-provoking things:—

> "Now it can clearly be argued that an aeroplane should be allowed to carry more when flying over cool, flat country between large sea-level aerodromes than when flying over mountains between high-up aerodromes in the tropics. I submit that the minimum safety requirements should vary with route conditions."[7]

We in the United States had the same idea. In the same month in which Roxbee Cox delivered his lecture, the Civil Aeronautics Board had adopted the first regulation in which we made any serious attempt to correlate the performance requirements imposed upon aircraft in interest of safety with the specific conditions of the route which the aircraft were to fly and the characteristics of the fields which they were to use. Our first attempt in that direction had the shortcomings of many initial efforts. After much further study, and protracted discussion with designers and airline operators and all other interested parties, it was revised into the form that is now in effect.

The underlying principle of the present regulations, insofar as they impose minimum limits of performance, is that it should be possible for a transport aircraft, under the actual condition of its operation, to sustain a failure of any one engine at any instant of the aircraft's flight without thereby creating any serious hazard; and that the standard requirements should include enough margins of performance to give reasonable insurance that the operation would still be safe in spite of high temperature, turbulence, or other sub-standard atmospheric conditions, sub-standard condition of the aeroplane, or failure to maintain the optimum flight path and air speed with the rigour which could be expected of a test pilot putting the type through its official trials. We have sought to make the regulations describe the conditions of an actual emergency as closely as practicable, and the certification trials of a new type are designed to simulate such emergencies.

The American airworthiness regulations now require that every new type of aircraft which is to be certificated for transport use shall undergo, in addition to suitable tests for stability and control, enough landing and take-off trials to make it possible to compute the landing and take-off paths with reasonable accuracy for any weight within the probable operating range of the aircraft, and for any altitude above sea-level. The landing distance is measured in still air from a height of 50 ft. above the ground to the point of bringing the aircraft to rest; and at the instant of passing the 50 ft. altitude the speed must be at least 30 per cent. in excess of the stalling speed, to keep the approach to a reasonable semblance of that which a transport pilot would use under actual operating conditions. The flaps or their equivalent must be so set that the rate of climb with take-off power will be at least 0.07 times the square of the stalling speed in miles per hour, so insuring the pilot's ability to pull up and continue his flight without being dependent upon instant retraction of the flaps in case he finds himself to be overshooting.

The landing distance having been thus determined for a suitable range of weights and altitudes, the requirement is imposed upon transport operators making use of the aircraft that it shall be so loaded for any particular flight that the landing distance as shown by the results of the official trials will not exceed

[7] "Looking Forward" by H. Roxbee Cox. Journal of the Royal Aeronautical Society, September, 1940, p. 695.

60 per cent. of the actual length of runway available at the field where the landing is to be made. It is thus assumed that the pilot will actually cross the edge of the field at an altitude of 50 ft.; and the margin provided by the 60 per cent. requirement is to allow for slippery runways, for imperfect brakes, for high air temperature, and for other deviations from normal.

The conditions with respect to take-off are substantially more complicated. The fundamental assumption in that case is that the take-off run is started on full power; that one engine stops at the most critical instant of the take-off; and that it must be possible, whatever the instant at which the engine failure occurs, either to continue the flight with safety or to bring the aeroplane to rest within the confines of the field. It is assumed that the retraction of the landing-gear is started at the instant of leaving the ground; and that the propeller of the dead engine continues to windmill until a height of 50 ft. is reached, whereupon the operation of feathering is started. The aeroplane must leave the ground at a speed at least 20 per cent. in excess of the power-off stalling speed, and at least 10 per cent. in excess of that at which it can be kept under full directional control.

The use of an aircraft in transport operation must then meet the requirement that no take-off may be made with a load greater than will permit the aircraft, in following the demonstrated path for the case of critical engine failure, to reach a height of at least 50 ft. by the time it reaches the edge of the field and thereafter to clear all obstructions by at least 50 ft. vertically or 300 ft. horizontally until it has attained an altitude completely clear of the surrounding terrain. It is further required that the rate of climb with any one engine inoperative and its propeller windmilling, and with the other engines operating at take-off power, shall be at least 0.035 times the square of the stalling speed of the aircraft with the flaps set as in the take-off tests.

Since an aeroplane may take off and land under very favourable conditions and yet have to pass over high and rugged terrain en route, the regulations include a further stipulation that the rate of climb with one engine stopped, the propeller feathered, and the remaining engines operating at the maximum rate of power for continuous output, must be at least 0.02 times the square of the stalling speed at an altitude 1,000 feet above the highest terrain that has to be passed in the course of the flight.

These requirements obviously impose a complicated specification upon the use of the flap, if the highest possible performance is to be secured from an aircraft under all operating conditions. Both landing and take-off are subject to the requirement that the aircraft shall have at least a certain minimum rate of climb with the actual flap setting with which the landing or take-off is to be executed. The minimum allowable rate of climb, being proportional to the square of the stalling speed, increases with the weight of the aircraft; whereas the actual rate of climb at a given flap setting will of course decrease either with increase of weight or increase of altitude. To qualify for the maximum possible load at low altitudes and into or out of small fields, the flap setting used for a given manœuvre must vary both with the current weight of the aircraft and with the altitude of the field. Since the pilot can scarcely be expected to work all that out during a difficult approach, such variation is allowed only upon the condition that it is built into the flap control. It is required that there be a pre-setting control, which the pilot may set for the altitude of the field that is to be used and for the anticipated weight at the time of landing or take-off, and an actual operating control, which may be moved merely to such indications as " take-off," " approach," or " landing." The flap must thereupon move automatically to the angle appropriate for the manœuvre indicated and for the weight and altitude for which the proper settings had previously been made.

To meet these conditions imposes a new set of restrictions on the designer's choice of fundamental design ratios. In order that an aeroplane may be intro-

duced into post-war transport service in the United States, if the present requirements remain unchanged, it will have to have a rate of climb of $0.035\ V_{stall}^2$ with one engine inoperative and its propeller windmilling. In the post-war state of the art as I now foresee it, that will be approximately equivalent to a requirement that the product of the power loading and the square root of the span loading should not exceed 21 in the twin-engine aircraft, or 30 in a four-engine one.[8]

The restrictions imposed on span loading by the take-off requirements may now be compared with the conclusions on span loading that were previously derived from considerations of cruising efficiency alone. The comparison can be made through the tabulation :—

Take-off power loading.	Probable cruising speed at 10,000 ft. (assuming W/S not in excess of 40)	Optimum span loading for cruising.	Maximum allowable span loading for single-engine climb at take-off in a twin-engine aircraft (assuming aspect ratio 12)
5	300	7·2	17.6
6	280	6·3	12.2
8	250	5·3	6.8
10	228	4·7	4·4
12	212	4·3	3·1
15	185	3·4	2.0

(The smaller of the two values of span loading is underlined in each case.)

With take-off power loadings of more than about 10, the ability to meet the regulatory requirements for climb with one engine inoperative becomes critical in determining the span loading in twin-engine aircraft.

For a twin-engine aircraft with an aspect ratio of 12, the product of take-off power loading and the square root of wing loading must not be more than about 72 if the machine is to comply with the American regulations. Except for twin-engine aircraft with a take-off power loading in excess of 14, this restriction is less severe than the restriction that the product of power loading and wing loading shall not be in excess of 300, which has been accepted as a rough criterion of margin of power in most of the preceding analyses of costs.

For operating from a field at an altitude of 5,000 ft., assuming the engines supercharged to develop full take-off power at that altitude, the corresponding maximum allowable values would be about 7 per cent. lower than for sea-level.

The requirements relative to single-engine operation en route become critical only when exceptionally high altitudes occur along the route to be flown. In general, any twin-engine aircraft that meets the take-off requirements will be able to show as much climb under continuous cruising conditions, with one engine inoperative, as is necessary to cross terrain at least 3,000 or 4,000 ft. above the level of the field from which the take-off was made.

The product of wing loading and power loading is somewhat less satisfactory as a criterion of distance required for take-off when one engine fails during the take-off run than it is in gauging take-off distance with full power. It still serves the purpose to a fair degree of approximation, however; and in Fig. 20 the minimum length of take-off runway likely to be required under the present American regulations is plotted against the value of the product of wing loading and take-off power loading for twin-engine and four-engine aircraft. On the

[8] In the specific case of the DC-3 with increased load, the maximum value of this product that is compatible with meeting the requirements of climb in the take-off condition is concluded from tests run by the United States Civil Aeronautics Administration to be 18.5. That would correspond to a load of 26,200lb. for the aircraft with 1200 h.p. engines, 1,000lb. in excess of the maximum at which it has heretofore been operated in regular air transport.

same chart there are included curves of the maximum power loading and minimum wing loading with which the several values of the product of wing loading and power loading can be realised without being liable to fall below the rate of climb with one engine inoperative that is required by the American regulations.

It appears that the necessary rate of climb can hardly be attained with a loading product of 500 in a twin-engine aircraft, for example, unless the wing

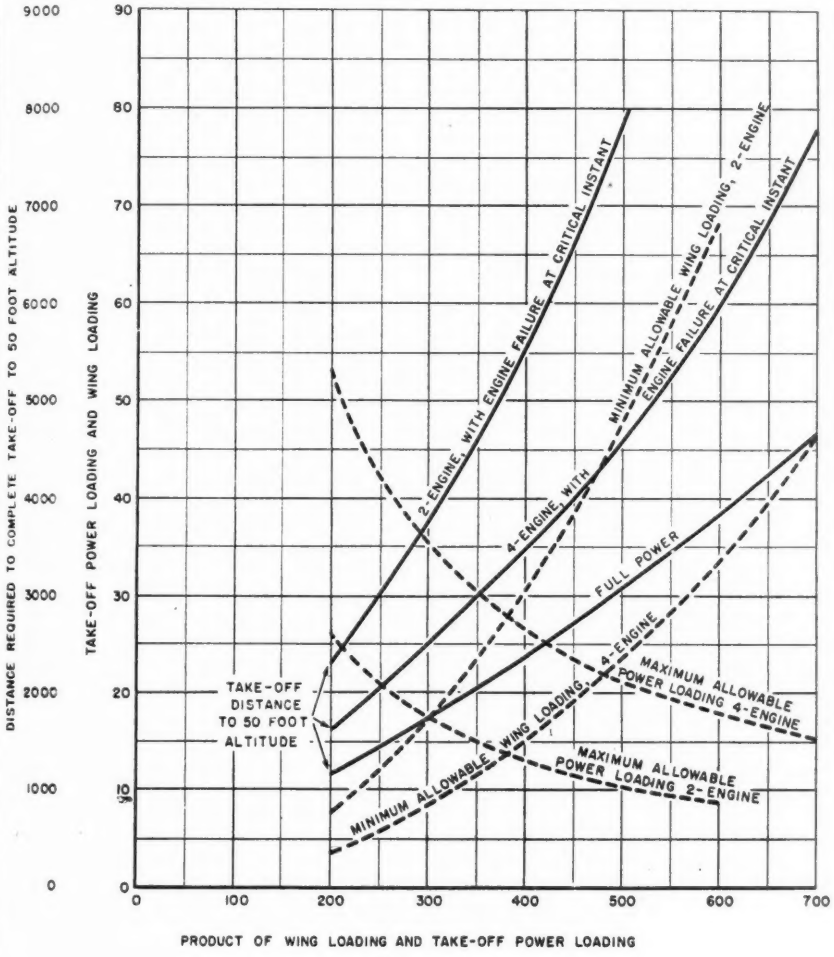


FIG. 20.

loading is at least 50 lb. per square foot and the take-off power loading less than 10 lb. per horse-power. These curves, like most of those previously presented, represent the best performance that seems reasonably likely for the very near future. The length of take-off required by transport aircraft actually in service at the present time, analysed in accordance with the present American regulations, may run as much as 25 per cent. in excess of the values given by the curves in Fig. 20.

Upon the assumptions used herein, the maximum wing loading that is allowable without undue increase in stalling speed becomes a limiting factor in seeking maximum economy of operation at speeds in excess of about 225 m.p.h. At speeds below that figure it is likely to be the take-off condition that is controlling. Specifically, under the present American regulations it is the requirement concerning single-engine climb immediately after take-off with one dead engine. The meeting of that requirement appears likely to increase the operating cost per payload ton-mile by from 10 to 15 per cent., in an aeroplane designed primarily for maximum economy rather than for speed, as compared with the best economy that could be realised if the possibility of an engine failure during or immediately after take-off could be completely disregarded.

Have we now carried elasticity in regulation, and the adaption of regulatory requirements to particular operating conditions, too far? Or not yet far enough? Certainly the new code is far more complex than the old. It has imposed upon the manufacturer the expense and delay of a series of tests, preliminary to certification, much more extensive than were necessary under the previous American practice or under that Annex to the I.C.A.N. which has governed British requirements. It has imposed upon the airline operators the necessity of making separate determinations of the maximum allowable loads for a given type of aircraft under a wide variety of conditions, with the load allowed at take-off dependent both upon the characteristics of the point of take-off and upon those of the airport at which the landing is to be made, and even on occasion upon the characteristics of the terrain to be crossed en route. In 1939 the specifications with respect to the landing and take-off performance of aircraft consumed only 16 lines of the American Civil Air Regulations. They now occupy 4½ pages. Yet it seems impracticable to secure a sufficiently definite statement in less compass, and I believe that there are few if any of the American manufacturers or operators who would forego the advantages of the flexibility of the new regulatory code in order to regain the simplicity of its predecessor.

If the policy of determining regulatory requirements by foreseeing the specific problems that may be expected to arise in a specific operation and requiring that the aeroplanes have enough margin of power to cope with them were to be pursued to its logical extreme, it is obvious that other factors in addition to those already embodied in the regulation could be taken into account. We know, for example, that some airport runways are surfaced with material which has an unhappy faculty of becoming slippery when moist, whereas in other cases the surfacing compound is such that the brakes hold almost as well on a wet surface as on a dry one. It is not wholly reasonable to require as great a margin of runway length in which to bring the aeroplane to rest, as compared with the stopping distance demonstrated in the certification trials, in the second case as in the first. Some regions are liable to ice-covered runways at any time during several months of the year, while in other areas ice is unknown. Some fields are subject to temperatures at 120°F., while in other cases nothing in excess of 75° has to be anticipated. Such factors have substantial effects on landing and take-off distances, and might be allowed for in the determination of maximum loads. I believe that as we get more experience there will be an increasing readiness to take still more variables into account; but up to the present time the response of the American industry to any suggestions that climatic conditions should be recognised as modifying the length of runway required for safe operations has been unfavourable, as presenting an undesirable degree of complication and variety.

I believe that we are on the right track in establishing this correlation between the characteristics of the aircraft and the characteristics of the route on which it is to be operated; and I believe that we shall see much more of the same sort of thing. I believe, and I earnestly hope, that we shall have a somewhat similar development with respect to civil aircraft not intended for transport

purposes. In transport operation the fundamental standard of Government regulation is the protection of the patrons, who have neither the capacity nor the opportunity to investigate such matters themselves, against any possible relaxation of standards or incurring of undue risks. With aircraft designed for use by private or industrial owners, on the other hand, it may better be the primary concern of Government to insure that the purchaser of the aircraft receives all the information that he needs in order to make his own decisions intelligently on the conditions under which he should operate. I am sorry to say that our regulations still present the anomalous situation, with respect to all aircraft except those in the transport category, of a rigid und unvarying requirement that the ability to get off the ground in 1,000 feet must be demonstrated as a condition of certification—notwithstanding the wide variety in the types of use to which the purchasers of aircraft wish to put them and in the size and character of the fields of which they will make habitual use. My own hope is for the replacement of the present provisions on that point by a requirement that the take-off performance of each new type of aircraft shall be officially determined, and the results be incorporated in the operating manual supplied to each user; but that is a matter which neither governmental authorities nor the aircraft industry are likely to find the time to discuss during the war.

In addition to the provisions relating to the determination of landing distance and take-off distance, the American regulations, unlike those drawn up under the I.C.A.N., provide for maximum limits on stalling speed. The general improvement in the smoothness and firmness of airport surfaces, and the steady increase in mechanical reliability and consequent decrease of the hazard of having to land elsewhere than on a regularly prepared airport surface,[9] have diminished the direct importance of the speed at which the aircraft makes contact with the ground. The speed of approach to a landing, however, is still a serious consideration. In making an approach in low visibility, whether by visual means or entirely on radio guidance, the pilot has to go through a certain sequence of operations and make certain decisions at intervals that are determined by the distance traversed rather than by the passage of time. Approach speed thereby acquires an absolute significance for safe operation under bad conditions, and it must be kept low enough so that the pilot will not be unduly crowded in the operations of the approach. The stalling speed of the aircraft has a direct bearing, also, upon turning radius and thereby upon the possibility of circling the field in low visability without losing visual contact with it.

It seems to be the prevailing view among experienced airline pilots in the United States that they do not want to have to make approaches, under present conditions, at over 120 m.p.h. Good practice seems to require also that the speed maintained during the approach should be at least 40 per cent. in excess of the stalling speed, to allow proper reserve for manœuvring and a proper margin of safety against stalling due to gusts. Combining the 120 m.p.h. with the 40 per cent. reserve indicates a stalling speed of 85 m.p.h., and that is the level at which American regulation currently sets the maximum allowable in the "approach condition." The approach condition is defined as including a flap setting which will allow the aircraft to retain a rate of climb with one engine stopped, with the remaining engines operating at take-off power, the landing gear retracted, and the propeller on the dead engine feathered, of at least $0.04\ V_{stall}^2$. Assuming a stalling speed of 80 m.p.h., the required rate of climb is 256 ft. per minute. Obviously, as in the case of the take-off, this implies a variation of the allowable amount of flap with altitude, and a rather rapid variation with altitude of the maximum allowable load.

[9] During the year 1942, in more than 100,000,000 miles of transport operation in the United States, there were only two cases in which a transport aircraft landed elsewhere than on a regular municipal airport as a result of power plant failure.

The loss of one engine characteristically reduces the full-power rate of climb by about 600 feet per minute in a four-engine transport aeroplane and 1,200 feet per minute in a twin-engine one.[10] The definition of approach condition typically operates, therefore, to limit the flap setting approximately to that with which a twin-engine aeroplane would have a full-power rate of climb of 1,500 ft. per minute or a four-engine aeroplane a rate of 900 ft. per minute. That, in turn, typically means that twin-engine aircraft can use relatively little flap in meeting the 85-mile stalling speed condition unless they have an exceptionally low power loading, while four-engine machines in meeting the same tests can depress the flap enough to secure, with a conventional flap, about three-fourths of its full effect on maximum lift coefficient.

There is a further limitation of maximum stalling speed in the landing condition, with full flap, to 80 m.p.h. I will not dwell on that, beyond saying that it becomes critical only for four-engine aircraft with a relatively low power loading.

The regulatory specification of flying qualities, and especially of stalling characteristics, is closely related to the regulation of performance. American ideas on that subject, too, have undergone rapid development in the past few years, in the direction of making specifications more exact, of increasing the use of numerically determinable standards, and of reducing the emphasis on dynamic stability requirements and replacing them with static stability criteria. I shall not discuss these matters in detail, but I am including as an appendix to the lecture the sections of the present American airworthiness regulations relating to flying qualities in the transport category.

It will be a problem of post-war planning to discover how far it may be possible to secure international uniformity in such matters as these. Obviously it is intrinsically desirable that airworthiness standards should be common to all the aircraft manufacturing and aircraft operating countries of the world. Agreement on such matters will enormously facilitate international trade in aircraft, and international air commerce. Non-uniform airworthiness requirements present fertile ground for the development of the evil suspicion that a foreign competitor, either in aircraft manufacture or in transport operation, is gaining an advantage in apparent performance or in operating cost by cutting safety standards. The suspicion may be unjustified, and usually will be, but it will still exist. On the other hand, it would be foolish to underestimate the administrative complications and the possible delays that a search for international agreement on a grand scale on those subjects would entail. Anyone who has lived through the process of making a major change in airworthiness requirements, by way of modernising them, must feel some trepidation at the thought of having to collect, consider, and as far as possible to reconcile the views of the interested parties of several continents, instead of those of only a single country. Uniformity must be sought; and no one will be better pleased than I if it can be carried to the last detail; but I am not wholly confident of the practical possibility of going beyond international agreement upon a rather general framework of the more vital provisions.

Regulatory Standards and Local Transport Services.

Regulatory authorities in all countries will have to face in future the question of the rigour with which the standards developed primarily for services carrying large numbers of passengers, and in most cases over fairly long distances, should be maintained for purely local transport operations with necessarily light loads. Small aircraft have great advantages in frequency and flexibility of service; but they bear a burden of increased cost that may limit their use in local services to cases in which the advantage over ground transportation is so enormous that relatively high rates of fare can be maintained (as in some over-water flights) or

[10] With extremely light power loadings, these figures may be raised to approximately 1,000 and 2,000 respectively.

to the inevitably limited number of cases that receive a generous and more or less permanent government subsidy. To overcome those limitations, every effort must be made to keep this increase of cost with decrease of size to a minimum.

One obvious possibility for cost reduction lies in the use of single-engine aircraft, manned by a single pilot.

Present American regulations impose a restriction, for future transport services carrying passengers within the continental United States, to multi-engine equipment having a substantial reserve of performance with any one engine inoperative.

As we look into the possibilities of local services, however, and of the provision of service for a large number of small communities spaced relatively close together, it seems harsh to tell the people who would be benefited that they cannot have transport service at all unless they can support the type of service that is operated between Chicago and St. Louis or London and Liverpool. The people of such communities can travel in single-engine aircraft by private charter, or by purchase and personal operation. They may well claim consideration of the use of single-engine machines in public transport, under proper restrictions, as a means of securing the establishment and survival of transport services that could hardly exist at all under any other conditions.

Fortunately the economic penalties of light wing loading are much less severe in small aircraft than in large; and if single-engine aircraft are to be allowed they can therefore be made subject to severe restrictions on stalling speed without sacrificing too large a proportion of the economic advantages of the single-engined arrangement in the smaller sizes.

I suggest as a possible regulatory form that the use of single-engine machines in public transport should be allowed on condition that their gross weight does not exceed 10,000 lb.; that the stalling speed is not over 55 m.p.h.; the demonstrated distance to complete a landing from a 50 ft. altitude not over 1,500 ft.; and that they are not to be so operated as to lose visual contact with the ground for any appreciable period, or on routes which will at any time carry them more than 10 miles from a field safely usable for an emergency landing. That again is a subject that has had no formal consideration in the United States; but I have set it down as one that is likely to deserve attention both in the United States and in all parts of the British Commonwealth. Certainly engine failure presents a hazard; but during the past year of transport operation in the United States there has been but one complete engine failure for every 3,000,000 engine-miles operated. Most of those failures did not come without some warning; and very few of them would have been likely to lead to any serious results if they had occurred in single-engine aircraft with a steep angle of descent and a low stalling speed. In Alaska, where the replacement of dog-drawn sledges by aircraft during the past 15 years has had a revolutionary effect on the economic life of the Territory, approximately 80 per cent. of the internal operation is with single-engine aircraft; yet in the 11,000,000 miles of air transport service rendered in Alaska in the years 1939 to 1941, under exceptionally difficult topographic and meteorological conditions, and with very little provision for radio communication or air navigation facilities, there were only seven fatal accidents.

The Future of Airports.

I turn now to the problem of future airport size, which is intimately related to the questions of economy of operation, of the prospective size and design characteristics of transport aircraft, and of the regulatory standards that are to be imposed, and to the degree of safety that is to be attainable.

No matter how large airports may be made, one may confidently anticipate that there will come a time when some particular airport will not have been large enough for a particular emergency; and when a pilot will feel that if the runways had only given him a few hundred feet more in which to bring the aeroplane to rest, the crash would have been averted. The larger the airport

is made to start with, however, the less likely such contingencies become; and even if no factor of risk to human life were involved, but only material damage, the cost of modern aircraft is so high in comparison with the annual fixed charges on airport surface as to make a very liberal policy appear the wise one.

From that point of view, however, and also from the point of view of the effect of airport dimensions on economy of operation, successive increases of size bring progressively diminishing returns. Obviously, a point is finally reached, as provision is made for a progressively longer take-off run, at which the minimum safe rate of climb rather than the take-off distance becomes the limiting factor.

Fig. 20 has shown how the length of runway that is profitably usable under existing American requirements with respect to the efforts of an engine failure during take-off is primarily a function of wing loading. Within the range of wing loading of from 20 to 45 lb. per square foot, the length of runway required for getting off in accordance with the regulatory requirements, while carrying the largest power loading that is compatible with securing the required climb with one engine inoperative, is approximately:—

$$L = 1{,}000 + 150\ (W/S)$$

The maximum usable length of runway ranges from a little over 3,000 ft. with a 15 lb. wing loading to nearly 8,000 with a loading of 45 lb. per square foot.[11] The distance so determined seems to be very nearly the same for twin-engine and four-engine aircraft; but the four-engine aircraft is of course able to operate, for a given wing loading, with a full-power loading about 40 per cent. higher than the twin-engine aircraft could sustain, and a consequent reduction of ton-mile operating cost.

The aircraft which is to take full advantage of a runway as long as the maximum just suggested would also require that the terrain surrounding the airport should be so free from obstruction that the climb could proceed on a slope of only about 1 in 100 after passing the edge of the airport, in the hypothetical case of sudden failure of one engine at the critical instant.

Assuming the use of highly efficient flaps, but without variable area devices, the existing stalling speed requirements may permit maximum wing loadings at the time of landing of approximately 32 lb. per square foot for twin-engine and 38 lb. per square foot for four-engine aircraft. The take-off loading may be increased above that figure by the amount of fuel that is to be used in flight; and for flights in the 500-mile range the maximum loadings at take-off might be increased to around 34 and 40 lb. per square foot respectively. With Fowler flaps or other devices of that sort it would of course be possible to go somewhat higher; but with the straight flap the maximum length of runway that would appear to produce any economic return in terms of increase in allowable take-off load, under the present American regulations, would be about 6,000 ft. for twin-engine and 7,000 ft. for four-engine aircraft.

With a given wing loading and span loading, the maximum power loading with which a rate of climb of $0.02\ V_{stall}^2$ with one engine inoperative can be attained at a height of 5,000 ft. should be about 20 per cent. greater than the maximum power loading with which the condition relating to climb immediately after take-off can be met. That, in effect, is the nature of the benefit derived from assisted take-off or refuelling in flight. It makes it possible to eliminate from the aircraft the weight of a certain portion of the power plant that would otherwise be required to get the aircraft safely into the air and for no purpose thereafter. The maximum effect of take-off assistance or refuelling on an aircraft which must be able to continue flight in the event of a failure of one engine is to reduce

[11] (These figures relate to airports at sea level. They increase only very gradually with altitude, however, as the maximum allowable power loading decreases almost rapidly enough with increase of altitude, under the terms of the regulations, to counterbalance the normal effect of altitude on airport runway length.)

the power, and the weight of the power plant, by about one-sixth. If, on the other hand, the failure of an engine while flying at full weight could be disregarded, on the assumption that the aeroplane would be lightened by dumping fuel in the event that such a failure occurred, power might be reduced by as much as a half in a twin-engine aeroplane or a third in a four-engine aeroplane, of available runway is materially less than that given by the formula :—

$$L = 1{,}000 + 150\ W/S$$

also, there would be a further saving in power as compared with the amount required for take-off. The increase of power loading that assisted take-off makes possible, however, is secured at the expense of a sacrifice in cruising speed.

Alternatively, assisted take-off may be viewed as permitting an increase of wing loading with a given power loading. On that basis the cruising speed, instead of being lower, would usually be somewhat increased; but the gain in maximum economy of operation would be relatively small as compared with the gain that could be made if the assisted take-off is used primarily to permit an increase of power loading.

Safety in Air Transportation.

No discussion of air transport developments could be complete without some mention of the notable improvements in the safety record that have been made in recent years, and of the means whereby the improvement may be continued. So far as the past is concerned, Fig. 21, which shows the passenger safety record of the airlines operating within the continental United States during the past 14 years, speaks for itself. I have departed from the common practice of using the number of passenger miles per passenger fatality as the criterion of safety, substituting the reciprocal of that ratio, since a function that gradually approaches zero lends itself more readily to graphical representation than does one that gradually approaches infinity.

The period covered by the curve roughly divides into three stages, each of reasonably stabilised accident record. They are :—

	Average passenger fatalities per 100,000,000 passenger miles.
1929-31	26.7
1933-37	7.8
1939-42	2.8

(1932 and 1938 are omitted, as transitional years.)

The average accident hazard dropped by approximately 70 per cent. in two years at the time when the first modern twin-engine aircraft were introduced. It dropped by another 60 per cent. between 1937 and 1939. In the worst year since 1933 the safety record has been more than twice as good as in the best year prior to 1932. Similarly, the worst year since 1939 has been 20 per cent. safer than the best year before 1938.

In appraising the chances of a further substantial reduction and the means of attaining it, it is useful to consider the circumstances of the accidents of the recent past and to see how far they could have been averted by measures which may be standard practice in future. Obviously, no examination on that basis can be conclusive; for the future will bring new problems, and may bring new troubles and causes of accidents for which nothing in the past has prepared us. Still it is true that accidents do repeat themselves in general character, and present a recurrence of common factors to a greater extent than is often realised.

Accidents which have a single cause are exceptional. Typically they are the result of a coincidence of unfavourable conditions; and if our primary interest is in accident prevention, rather than in post-mortem for its own sake, our

problem is to discover which one of the contributing factors could most readily have been so changed that the accident would not have occurred.

Accidents in which human error appears as a major cause, for example, fall into two classes. The first class comprises the cases (very few, among airline personnel) in which recklessness or carelessness was responsible, and in those instances we may best hope for correction either by a more careful selection of personnel or by better training and improvement of *esprit de corps*. The second group, which is much the larger of the two, includes the accidents due to errors of judgment or of technique. In those cases there is no factor of deliberate action; but a particular individual, at a particular time and place, encountered conditions with which he was unable to cope, although some other

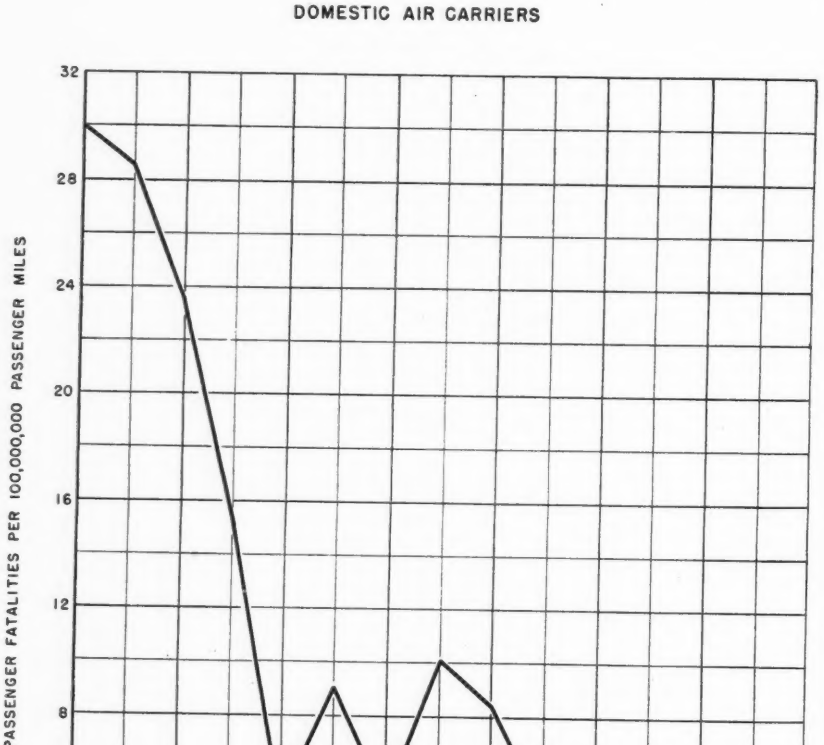


FIG. 21.

individual, or the same one on some other day, could have done so. The variability of human judgment under pressure has been inherent for some hundreds of thousands of years. Even the most carefully selected and highly skilled personnel are unlikely to become immune to such errors if the problem presented to them for solution is sufficiently difficult; but we can very often improve the conditions under which they operate, and reduce the likelihood of personal error by increasing the margin of safety within which they work.

In stressing the importance of improvement in operating conditions and mechanical aids, I do not want to underestimate the human factor. The highest possible order of ability, the maintenance of untiring vigilance by every individual engaged in air transportation, and the existence in every individual of a personal sense of responsibility for the success of the whole operation, are absolute fundamentals. The best present hope of reduction in that considerable proportion of accidents which are ascribable to errors in judgment or in technique does not lie in further improvement in the quality of the personnel concerned, however, but in reducing the difficulties of their task. If a number of people were given the task of following a two-foot wide footpath without falling off, the percentage of personal error would be infinitesimal; but if the two-foot width were reduced to the width of a two-inch plank, and raised to a considerable height above the ground, the number of errors would become large.

In the past four years there have been 12 fatal accidents on airlines within the United States, in 430,000,000 miles of flying. Seven of that number occurred while making approaches for landings. In two of the seven cases the pilots were confused about their location; in two more they were landing on comparatively short runways; in two cases the pilots were either approaching the field or circling it under a low ceiling; and in the final instance there appears to have been an error in setting the altimeter, with resultant collision with the ground during an approach at night.

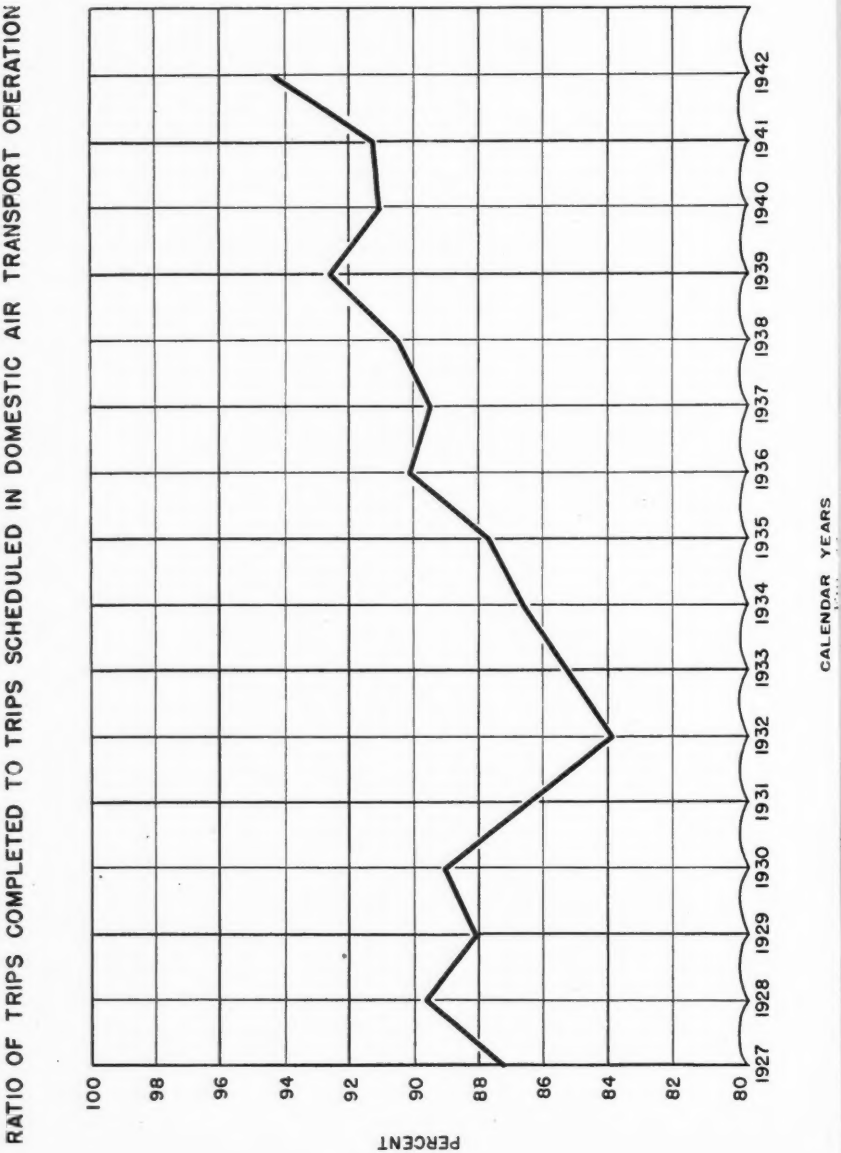
With radio navigation facilities brought into line with the best present state of the art; with instrument-landing installations generally available; and with margins of safety in airport dimensions as generous as are incorporated in most recently-built airports, at least four, and very probably five or six, of those accidents would have been averted.

In two instances, including one of the seven cases of landing approach previously mentioned, the pilots appear to have made errors, despite generally favourable conditions, which should have been unnecessary. The proportion of such errors has been very small indeed; but even that small number of failures could have been averted by a more complete routine of checking between the pilot and co-pilot; or by better *esprit de corps*, with its accompanying determination on the part of every individual that he would be no party to taking chances, cutting corners, or taking anything for granted. In one of the four remaining cases, a transport was run down from behind by another aircraft. In only one instance in the four years does any mechanical failure of airframe, engine, or any accessory appear to have played a part. One of the accidents was attributed, although somewhat speculatively, to lightning; and one remains a complete mystery.

In only two of the twelve cases was ice on the aircraft involved, and in neither of those instances was the icing so severe as to have made the accident inevitable if the airport conditions had been as good and the navigational aids as highly developed as we may reasonably hope that they typically will be after the war. In no instance was there fire in the air. Not a single fatal accident involved a breakdown of radio communication or the failure to understand a spoken message correctly; and it is a high tribute to the efficiency of the organisations controlling air traffic that no fatal accident in air transport has involved any error in traffic control, despite the millions of reports that have to be received and used as a basis for the issuance of instructions, and the pressure under which the controllers work. The burden on traffic control is

going to continue to increase, however; and, as against the categories of accident which should clearly diminish in frequency under post-war conditions, it will require the most careful planning to keep the hazard of collision in the air from increasing with increase of congestion of the air space.

Obviously, the greatest opportunities for future improvement lie in the development of better air navigation facilities, including a general provision of instrument-



landing means, and larger and better lighted airports. Next in importance is the continued development of operating routines for enabling personnel to check themselves and each other, and the acceptance of the strictest possible adherence to standard procedures, except when an emergency demands departure, as the surest means of overlooking nothing and of avoiding confusion. By those means alone, with the facilities that seem likely to be available very soon after the war, at least half the accidents of the last four years would have been eliminated. It requires nothing that is not definitely in prospect at the present time, and no anticipation of any change in the fundamental characteristics of transport aircraft, to justify an expectation that the accident rate can, within a short time, be reduced to a long-term average of no more than 1.0 fatality per 100,000,000 passenger-miles.

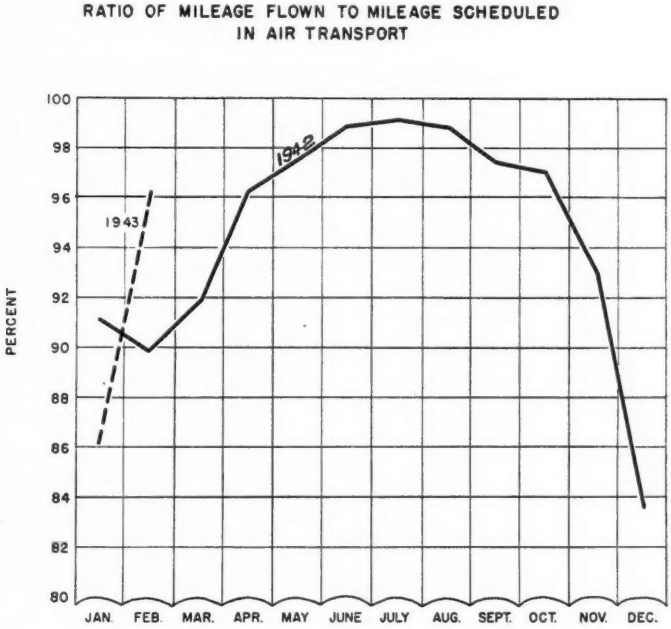


FIG. 23.

REGULARITY OF SERVICE.

Air transport has had many advantages over the older established surface forms, but it has laboured under the disadvantage of a substantially greater liability to cancellation of schedule than characterises its slower competitors. Regularity, like safety, may be examined in terms of what it has been in the years past and of what it ought to be in the near future in the light of promised technical development.

The customary American measure of regularity is the proportion of scheduled mileage which is actually flown. Fig. 22 shows its variation over the past 16 years on the domestic airlines of the United States taken as a whole. The irregularities in the curve are due in large part, if not entirely, to variations from year to year in the amount of bad flying weather during the winter. In the early years there was a tendency to decrease in regularity of operation which was probably attributable to the steady increase in the proportion of total

mileage having to be flown at night; but since 1932 there has been a gradual improvement that has brought the average performance from around 84 per cent. in that year to 94 per cent. now.

Regularity of operation and safety obviously have an inverse relationship. Undoubtedly the present number of cancellations and uncompleted trips could be reduced by at least a half at the present time, but it would be at the expense of a substantial increase in the number of accidents. The vice-president in charge of operations of one of the major airlines of the United States says of present practice, in a personal letter:—

> "Weather conditions actually experienced indicate that more than one-half of the trips cancelled because of anticipated weather conditions could have been flown within operating limits; but they were cancelled because of our inability to forecast weather perfectly and our desire to make errors on the conservative side."

The problem of regularity is to consider how far and how rapidly it can be increased while at the same time an improvement in safety record is continued. I take it as axiomatic that regularity is not to be sought at the cost of an increase in hazard.

The seasonal variations in regularity are of course very great. In Fig. 23 the percentage of scheduled mileage flown is plotted by months through 1942 and the first two months of the present year. In the winter months the national average shows from 10 to 18 per cent. of uncompleted mileage. In summer it drops to two per cent. or less. The possibility of improvement, at any season, depends upon the present causes of the cancellations and upon the extent to which the causes are individually eradicable.

We keep no official records on the causes of failure to operate particular trips; and I have therefore had recourse to the expert judgment of various airline officials who have been good enough to give me their estimates of the relative importance of the several factors that may interfere with operations. The average of their figures is shown in the tabulation:—

	Proportion of responsibility for cancellations and uncompleted trips during winter months.	Proportion of total number of scheduled trips cancelled, assuming overall winter performance factor of 85 per cent.
Low visibility and ceiling at take-off point or anticipated at destination	70	10.5
Icing conditions in the air	12*	1.8
Bad airport conditions for take-off or landing (snow, ice, etc.)	6*	0.9
Turbulence or storm (aside from violence of wind, covered in next item)	6	0.9
Anticipation of head winds too strong to be flown against	2	0.3
Mechanical trouble	4	0.6

* Average proportions for the middle to northern parts of the United States. These figures would be higher in the extreme north, much lower in the south, and probably substantially lower in western Europe.

How much improvement may be hoped for in the near future? Certainly the brightest prospect of reduction relates to the factor that is responsible for most of the delays and interruptions now. European operators had already had much experience with the Lorenz system before the war. I hope your experience will not make you think me over-sanguine in believing that within three years after the end of the war the use of instrument landing systems will have made it possible to lower present minimums of allowable ceiling and visibility to such

an extent that regular operations can be carried on on 75 per cent. of the occasions when they would now be cancelled because of cloud or fog, and at the same time to make the improvements in landing safety that I have previously foreseen.

That alone would eliminate more than 50 per cent. of all the present cancellations in winter, and a substantially larger proportion than that in summer; but there are other prospects also. De-icing by heat is on the way. It may not enable operations to be carried on regularly through the heaviest icing conditions, but it seems conservative to anticipate that it will reduce the present proportion of cancellations from that source by half. Airport maintenance improves as the volume of use of the airport and the dependence of the community upon air transportation increases; and interruptions by bad airport conditions will be reduced in future because they will not be endured, and the necessary measures will be taken to restrict them to the rarest occasions of extraordinarily bad weather. Less progress may be made in overcoming the other causes that I have enumerated; but fortunately they are of relatively little importance.

The aggregate promise for the immediate post-war period is for a reduction of between a half and two-thirds in the present number of failures of service. It does not seem too much to expect that under the operating conditions of the continental United States, the British Isles, or Western Europe the regularity of performance will rise to some 91 to 97 per cent. in winter and well over 99 per cent. in summer.

The world is full of promises of miracles to come; and the more optimistic prophets have heralded a new day in which surface transportation will moulder into a dingy obsolescence. I have had no miracles to offer. I have limited myself to what seems clearly visible; but even that circumscribed view has its excitements. The most modest anticipation cannot doubt that the technical development will be great. It will be for the people of the United Nations and their governments, and in particular and in large part for the nations of the British Commonwealth and for the United States, to determine how technical progress will be used. When the last bomb has been dropped, and unconditional surrender has become a fact in Tokyo and in Berlin, that problem will confront us. The success with which it is solved will shape the destinies of children yet unborn. The designers will not fail. The statesmen, and the peoples whose interests the statesmen serve, must not.

Appendix I.

Flying Quality (Stability and Control) Requirements Contained in U.S. Airplane Airworthiness Specifications (Part 04 of U.S. Civil Air Regulations) as of May 1st, 1943.

04.7511—*T. Stalling Speeds.*—In the following sub-sections of para. 04.75—*T*: V_{s1} denotes the true indicated stalling speed in miles per hour with engines idling, throttles closed, propellers in low pitch, and with the airplane in all other respects (flaps, landing gear, etc.) in the condition existing in the particular test in connection with which V_{s1} is being used.

04.754—*T. Flight Characteristics.*—There shall be no flight characteristic which makes the airplane unairworthy. The airplane shall also meet the following requirements under all critical loading conditions within the range of center of gravity, and, except as provided in 04.7541 (*d*), at the maximum weight for which certification is sought.

04.7540—*T. Controllability and Maneuverability.*—The airplane shall be controllable and maneuverable during take-off, climb, level flight, glide, and landing, and it shall be possible to make a smooth transition from one flight condition to another, without requiring an exceptional degree of skill, alertness, or strength on the part of the pilot, under all conditions of operation probable

for the type, including those conditions normally encountered in the event of sudden failure of any engine. It shall be possible, with power off, with flaps either retracted or in the landing position, with the center of gravity in the most unfavorable location within the certificated range, and with the airplane trimmed for a speed of 1.4 V_{s1}, to change the flap position to the opposite extreme, to make a sudden application of take-off power on all engines, or to change the speed to any value between 1.10 V_{s1} and 1.70 V_{s1}, without requiring a change in the trim control or the exertion of more control force than can be readily applied with one hand for a short period. It shall not be necessary to use exceptional piloting skill in order to prevent loss of altitude when flap retraction from any position is initiated during steady horizontal flight at 1.1 V_{s1}, with simultaneous application of not more than maximum-except-take-off power.

04.7541—*T*. *Trim*.—The means used for trimming the airplane shall be such that after being trimmed and without further pressure upon or movement of either the primary control or its corresponding trim control by the pilot or the automatic pilot, the airplane will maintain:—

(*a*) Lateral and directional trim under all conditions of operation consistent with the intended use of the airplane, including operation at any speed from best rate of climb speed to high speed, and operation in which there is greatest lateral variation in the distribution of the useful load;

(*b*) Longitudinal trim, under the following conditions:—

(1) During climb at the best rate of climb speed with maximum-except-take-off power.

(2) During a glide with power off at a speed not in excess of 1.4 V_{s1} and

(3) During level flight at any speed from 90 per cent. of high speed to the sum of V_{s1} and 20 per cent. of the difference between high speed and V_{s1};

(*c*) Rectilinear climbing flight with the critical engine inoperative, each other engine operating at maximum-except-take-off power and the best rate of climb speed under such conditions;

(*d*) Rectilinear flight with any two engines inoperative and each other engine operating at maximum-except-take-off power under the following conditions:—

(1) With the weight of the airplane not more than that at which there is a speed range in level flight of not less than 10 miles per hour;

(2) With the speed of the airplane not more than the high speed obtained under the conditions specified in (1) less 10 miles per hour.

04.7542—*T*. *Stability*.—The airplane shall be longitudinally, directionally and laterally stable in accordance with the following provisions. Suitable stability and control "feel" may be required in other conditions normally encountered in service if flight tests show such stability to be necessary for safe operation.

04.75420—*T*. *Static Longitudinal Stability*.—In the flight conditions described in the following sub-section 04.754200—*T*.

(*a*) At any speed which can be obtained without excessive control force and which is more than 10 miles per hour above or below the specified trim speed, but not greater than the appropriate maximum permissible speed or less than the minimum speed in steady unstalled flight, the characteristics of the elevator control forces and friction shall be such that:—

(1) A pull is required to maintain speeds below the specified trim speed and a push to maintain speeds above the specified trim speed.

(2) The control will, when unrestrained by the pilot, move continuously toward its original trim position.

(*b*) Where a stable slope of the stick forces versus speed curve is specified, any decrease in speed below trim speed shall require an increase in the steady pull on the elevator control and any increase in speed above trim speed shall require an increase in the steady push on the control. Such slope shall be between such limits that any substantial change in speed is clearly perceptible to the pilot through a resulting change in stick force, and that the stick force required to produce necessary changes in speed does not reach excessive values.

04.754200—*T. Specific Stability Conditions.*—(*a*) *Landing.*—With flaps in the sea level landing position, the landing gear extended, maximum sea level landing weight, the airplane trimmed at 1.4 V_{s1} and throttles closed, the stick force curve shall have a stable slope at all speeds between 1.1 V_{s1} and 1.8 V_{s1}.

(*b*) *Approach.*—With flaps in sea level approach position, landing gear retracted, maximum sea level landing weight, the airplane trimmed at 1.4 V_{s1} and with power sufficient to maintain level flight at this speed, the stick force curve shall have a stable slope at all speeds between 1.1 V_{s1} and 1.8 V_{s1}.

(*c*) *Climb.*—With flaps retracted, landing gear retracted, maximum sea level take-off weight, 75 per cent. of maximum-except-take-off power and with the airplane trimmed at 1.4 V_{s1}, the stick force curve shall have a stable slope at all speeds between 1.2 V_{s1} and 1.6 V_{s1}.

(*d*) *Cruising.*—With flaps retracted, maximum sea level take-off weight, 75 per cent. of maximum-except-take-off power, and with the airplane trimmed for level flight, the stick force curve shall have a stable slope at all speeds obtainable with reasonable stick forces between:

(1) 1.2 V_{s1} and the maximum permissible speed, when the landing gear is retracted;

(2) 1.2 V_{s1} and the level flight speed, when the landing gear is extended.

04.75421—*T. Dynamic Longitudinal Stability.*—The airplane shall not be dynamically unstable longitudinally, as shown by the damping of the normal long period oscillation, under any flight condition that is likely to be maintained for more than 10 minutes in ordinary service. Compliance with this requirement shall be demonstrated under at least the following conditions:—

(*a*) During level flight with 75 per cent. of maximum-except-take-off power.

(*b*) During a climb with 75 per cent. of maximum-except-take-off power at a speed equal to 75 per cent. of that obtained in item (*a*) above.

Any short period oscillation occurring between stalling speed and maximum permissible speed shall be heavily damped with the primary controls in a fixed position.

04.75422—*T. Directional and Lateral Static Stability.*—The static directional stability, as shown by the tendency to recover from a skid with rudder free, shall be positive for all flap positions and symmetrical power conditions, and for all speeds from 1.2 V_{s1} up to the maximum permissible speed. The static lateral stability, as shown by the tendency to raise the low wing in a sideslip, shall be positive within the same limits.

04.7543—*T. Stalling.*—With power off, and with that power necessary to maintain level flight with flaps in approach position at a speed of 1.6 V_{s1}, maximum landing weight, flaps and landing gear in any position, and center of gravity in the least favorable position for recovery, it shall be possible to produce and to correct roll and yaw by unreversed use of the aileron and rudder controls up to the time when the airplane pitches in the maneuver described below.

During the pitching and recovery portions of the maneuver it shall be possible to prevent appreciable rolling or yawing by normal use of the controls.

In demonstrating this quality, the order of events shall be:—

(*a*) With trim controls adjusted for straight flight at a speed of 1.4 V_{s1} reduce speed by means of the elevator control until the speed is steady at slightly above stalling speed; then

(*b*). Pull elevator control back at a normal rate until a stall is produced as evidenced by an uncontrollable downward pitching motion of the airplane, or until the control reaches the stop. Normal use of the elevator control for recovery may be made after such pitching motion is unmistakably developed.

In any case, the airplane shall not pitch excessively before recovery is completed.

The airplane shall be recoverable without difficulty or the use of power from the inoperative engine when it is stalled with the critical engine inoperative and the remaining engines operating at 75 per cent. of maximum-except-take-off power.

Dr. Roxbee Cox, Vice-President of the Society, *Fellow*: I will first read, at the President's request, a cable from Mr. Orville Wright, in reply to the customary cable addressed to him on the occasion of the Wilbur Wright lecture, and a cable from Major Lester Gardner, Executive Vice-President of the Institute of Aeronautical Sciences:—

"On May 27th your distinguished countryman, Dr. E. P. Warner, will deliver the 31st Wilbur Wright Memorial Lecture before the Royal Aeronautical Society on 'Post War Air Transport.' The Council and all members of the Society send you once more their cordial greetings on an occasion when Dr. Warner is drawing our attention to the inestimable benefits which the aeroplane will bring to the world when the war has come to its inevitable end.—Gouge, Pritchard."

"On the occasion of the Thirty-First Wilbur Wright Memorial Lecture I send the Officers and Members of the Royal Aeronautical Society my cordial greetings. Were Wilbur here to-day he would be shocked at the havoc the aeroplane has wrought, but I believe with slight variation the old saying still holds good 'That he that liveth by the sword shall die by the sword,' and that we may now look forward with confidence to the post-war era of which my good friend Dr. Warner will speak.—Orville Wright."

"May the Wilbur Wright Memorial Lecture by our distinguished countryman, Edward P. Warner, be a successor to the other great contributions to aeronautical knowledge.—Institute of the Aeronautical Sciences."

Continuing, Dr. Cox said: And now I have the honour and the pleasure of proposing a vote of thanks to a distinguished lecturer and an old friend. For not only is Dr. Warner, as you are all aware, pre-eminent in the aeronautical community of the United States, but he is also the good friend of this country, of the Royal Aeronautical Society and of many of its members, all of whom, every time they meet him, are amazed afresh at the many-sidedness of his knowledge and the variety of his accomplishments.

To us, in fact, he is something of a phenomenon, and not only because of his personal gifts or because he has this evening delivered a classic lecture at a cracking pace, but because he is that rare bird, an engineer who has attained to high administrative office. Further, he has shown how good an administrator a first-class engineer can be.

It would be easy to continue at some length to talk of Dr. Warner's many qualities, and of the high esteem in which we hold him, but he is a modest man and I will spare him. I must, however, refer to his notable gift, so well demon-

strated by his lecture, for collecting, sifting, collating and presenting information. There are many of us here deeply interested, and in fact much concerned, about the future of air transport in the British Empire. We realise that there is so much to be done before we can give the Empire the trunk routes worthy of it. We have had long experience on the Empire routes in the past, but we know that we have still a lot to learn. There is, in fact, a deficiency of information in the economic field, and those of us who have sought to plan tentative courses through the mists of the future, have cried impatiently, as did our greatest criminologist to his chronicler, "Data, data, data." Dr. Warner must have heard, and here in the Wilbur Wright lecture is the data we want, served up on a plate—not cooked of course—a large meal for these times, but a digestible, appetising and nourishing one.

I think it would be difficult to exaggerate the importance of the statement which Dr. Warner has prepared or to overpraise the manner of its presentation. There will, therefore, Mr. President, be a very real gratitude in forming our vote of thanks to Dr. Warner for the 31st Wilbur Wright lecture, the 12th by a citizen of the United States of America, and the fourth of this war. These war lectures are to some of us mile-stones in the history of this conflict. The first took place in the midst of the sorrow of Dunkirk, the second at the end of the period in which we stood alone, the third when the tide was beginning to turn, and the fourth takes place at the end of a year of great Russian victories and Allied success in North Africa. These mile-stones mark a progression in our fortunes, so that perhaps it may not be too optimistic to hope that the next Wilbur Wright lecture will mark a degree of success not far removed from complete victory.

As I have said, twelve of the Wilbur Wright lectures have now been given by Americans. In recent years we have settled down to an alternation between United States and British lecturers. A similar arrangement seems to be developing around the Wright Brothers' lecture of the Institute of the Aeronautical Sciences, and these pleasant pendulums, swinging from one side of the Atlantic to the other, are indices of the close co-operation which exists between British and American aeronautical engineers and scientists, and which both parties, I know, wish to see ever more intimate and fruitful. Such collaboration is a very pleasant thing, and it is the earnest hope of all of us that the happy relations which always develop when technical men of all nationalities get together, so well exemplified by Anglo-American technical co-operation, are an earnest of collaboration in wider fields and a good omen for the lasting peace of the world when victory has been gained.

We are on the eve of tremendous developments in air transport. We look forward to a future which will, through the aeroplane, give to mankind in greater measure than ever before the tremendous benefits of travel and intercourse between peoples. This great future must be builded upon rock, the sturdiest layers of which must be safety and economy. This is why to-night's lecture, with its generous exposition of American economic experience, and its careful extrapolations and wise deductions therefrom, is of so much value to us, and I have very great pleasure, Mr. President, in moving that a hearty vote of thanks be accorded to Dr. Warner for it.

Lord BRABAZON OF TARA, Past-President of the Society, *Fellow*: It is my privilege to second the vote of thanks. We had now had three visits from Dr. Warner during the war, and he would like to make an appeal to His Excellency, Mr. Winant, who was present among the audience, to see that we had a visit every year from Dr. Warner, because he was such a handy man to have around. Instead of delving into difficult technical books, all one had to do was to ask Dr. Warner, who was the best example of a walking encyclopædia that the world had to show.

His lecture was both comprehensive and exhaustive. He (Lord Brabazon) had taken it to bed with him and tried to study some of the graphs—with the result that he had ricked his neck and nearly fallen out of bed. Seriously, there was a great deal of " meat " in it. Generally speaking, he considered that Dr. Warner's outlook on the future of Civil Aviation must be looked upon as conservative. But when we consider that heavy bombers to-day already weigh 60,000 lbs., we are faced with the question as to what is to be the jump from this to the great civil aviation transport planes. In other words, shall we merely see an increase from 60,000 to 150,000 lbs., or will it go right up to 500,000 lbs.? Dr. Warner's paper was very helpful, because he gave figures to act as a warning and show that not all problems are to be solved by size, and not all prizes are to the swift. His courage in tightening up the Airworthiness Certificate was much to be commended, because, after all, safety is the basis of Air Transport. A few figures would show the importance of this point:—

In 1939-1942 the number of people killed in air accidents was 2.8 per 100,000,000 miles; whereas in rail transport the figure was 0.1 per 100,000,000 miles. Therefore on the face of it, it was 30 times more dangerous to fly than to go by rail. In 1929, it was 300 times more dangerous to go by air than by train. (It should be pointed out, however, that in order to get killed it was necessary to travel, on an average, some 38,000,000 miles!)

In present circumstances, when aircraft are so mixed up with bomb raids, war and death, this lecture came like a breath of fresh air, showing that man's greatest invention still holds out promise to bind the world together for common endeavour and mutual understanding. If bigoted war-like narrow nationalism was to be broken down, then Civil Aviation would be fully able to bring about the new combine.

Dr. Warner's thoughts were in the air, but his feet were always on the ground; he was air-minded without being light-headed. To many people present he was an old friend. How welcome he is, each time he comes to this country, not only as a friend but also as an inspirer, making us think of the future. We thank him from the bottom of our hearts for the serious, useful and inspiring paper that he has read to us to-night.

Following the lecture the Annual Council Dinner was held at which the following were present:—

His Excellency the Duke of Alba, G.C.V.O. (the Spanish Ambassador).
Professor L. Bairstow, C.B.E., F.R.Ae.S. (Zarahof Professor of Aeronautics, Imperial College).
Sir Percy Bates, Bt., G.B.E. (Chairman, Cunard White Star Line).
Captain H. H. Balfour, M.C., M.P. (Parliamentary Under-Secretary of State for Air in the House of Commons).
The Rt. Hon. Viscount Bennett.
His Excellency Senor Don Manuel Bianchi (the Chilean Ambassador).
Mr. Robert Blackburn, O.B.E., A.M.Inst.C.E., M.I.Mech.E., F.R.Ae.S. (Blackburn Aircraft, Ltd., Member of Council).
Air Chief Marshal Sir Frederick Bowhill, G.B.E., K.C.B., C.M.G., D.S.O., F.R.G.S. (Chief of Air Transport Command).
Rear-Admiral D. W. Boyd (Chief of Naval Air Equipment).
Lord Brabazon of Tara, M.C., P.C., F.R.Ae.S. (Past-President of the Society).
Mr. Griffith Brewer, Hon. F.R.Ae.S. (Past-President of the Society).
Mr. A. C. Brown, B.Sc., F.R.Ae.S. (Fairey Aviation Company, Ltd., Member of Council).
Colonel H. G. Bunker (Chief of Air Technical Section, U.S. Forces).
Mr. W. A. M. Burden (Assistant to the U.S. Secretary of Commerce).
Dr. H. Roxbee Cox, D.I.C., B.Sc., F.R.Ae.S. (Deputy Director of Scientific Research, Member of Council).

The Rt. Hon. Sir Stafford Cripps, K.C.B., M.P. (Minister of Aircraft Production).
Air Marshal R. M. Drummond, C.B., O.B.E., D.S.O., M.C. (Air Member for Training, Air Ministry).
Mr. E. C. Gordon England, F.R.Ae.S. (Member of Council).
Sir Richard Fairey, F.R.Ae.S. (Director General, British Air Commission, U.S.A.).
Sir Roy Fedden, M.B.E., D.Sc., F.R.Ae.S. (Past-President of the Society).
Mr. A. Gouge, B.Sc., F.R.Ae.S. (President of the Society).
Major F. B. Halford, F.R.Ae.S. (de Havilland Aircraft Company).
Mr. W. P. Hildred, O.B.E., M.A. (Director General of Civil Aviation).
Mr. J. E. Hodgson, Hon. F.R.Ae.S. (Honorary Librarian of the Society).
Sir Harold C. Howitt, D.S.O., M.C. (Vice-Chairman of British Overseas Airways Corporation).
Professor Sir B. Melvill Jones, F.R.Ae.S. (Chairman, Aeronautical Research Committee).
Mr. O. T. Larson (Vice-President, Trans-Canada Air Lines).
Captain A. G. Lamplugh, F.R.Ae.S. (Honorary Treasurer of the Society).
Air Marshal Sir Trafford Leigh Mallory (Chief of Fighter Command, R.A.F.).
Captain A. I. Malstrom (U.S. Naval Air Attaché).
His Excellency Baron de Cartier de Marchienne (the Belgian Ambassador).
Major R. H. Mayo, O.B.E., M.A., F.R.Ae.S. (Member of Council).
Sir Frederick Handley Page, C.B.E., F.R.Ae.S. (Handley Page, Limited).
Mr. R. K. Pierson, O.B.E., B.Sc., F.R.Ae.S. (Chief Designer, Vickers Armstrong, Ltd., Member of Council).
Mr. G. E. Petty, F.R.Ae.S. (Blackburn Aircraft, Ltd., Member of Council).
Captain J. Laurence Pritchard, Hon. F.R.Ae.S., A.F.I.Ae.S. (Secretary of the Society).
Dr. A. G. Pugsley, F.R.Ae.S. (Royal Aircraft Establishment, Chairman of a Committee of Council).
Dr. D. R. Pye, C.B., F.R.S., M.A., F.R.Ae.S. (Provost of University College, London, Member of Council).
Mr. E. F. Relf, F.R.S., A.R.C.Sc., F.R.Ae.S. (Superintendent, Aerodynamics Department, National Physical Laboratory, Member of Council).
Mr. N. E. Rowe, B.Sc., D.I.C., F.R.Ae.S. (Director of Technical Development, Ministry of Aircraft Production, Member of Council).
Mr. A. E. Russell, B.Sc., F.R.Ae.S. (Chief Designer, Bristol Aeroplane Company, Ltd., Member of Council).
Lord Sempill, A.F.C., F.R.Ae.S. (Past-President of the Society).
Sir Francis Shelmerdine, O.B.E., C.I.E., F.R.Ae.S. (Member of Council).
Air Marshal R. Sorley, D.S.C., D.F.C., A.F.R.Ae.S. (Controller of Research and Development, Minister of Aircraft Production).
The Rt. Hon. Sir Archibald Sinclair, Bt., P.C., C.M.G., M.P. (Secretary of State for Air).
Mr. R. S. Stafford, A.F.R.Ae.S. (Handley Page, Ltd., Member of Council).
Air Marshal B. E. Sutton, K.B.E., C.B., D.S.O., M.C. (Air Member for Personnel, Air Ministry).
Major R. H. Thornton, M.C. (Alfred Holt and Co., Liverpool).
Mr. A. Hessell Tiltman, B.Sc., F.R.Ae.S. (Member of Council).
Lieut.-Col. M. M. Turner (U.S. Military Air Attaché).
Mr. Edwin C. Walton (Harriman Mission).
Dr. E. P. Warner, Hon. F.R.Ae.S. (Vice-Chairman, Civil Aeronautics Board).
Mr. J. G. Wilson (Director-General of Civil Aviation, Canada).
Mr. H. E. Wimperis, C.B.E., F.R.S., F.R.Ae.S. (Past-President of the Society).
His Excellency Mr. John Winant (the American Ambassador).
Mr. L. A. Wingfield, M.C., D.F.C., A.R.Ae.S. (Solicitor of the Society).

R.A.F. IN RUSSIA.

H. Griffith. Hammond, Hammond and Co., Ltd. 1942, 5/- net.

Flight Lieutenant Griffith has written the story of No. 151 Wing, R.A.F., in North Russia, which went out to Russia to teach Russian pilots how to fly, erect and maintain Hurricane aircraft; and also to demonstrate on the Germans the usefulness of the twelve-gun Hurricane in action.

As Flight Lieutenant Griffith states early in his book, " A short, informed, but not-too-official record of the doings of No. 151 Wing, R.A.F., in North Russia may be of some interest to the general public."

There is much of extreme interest on the " not-too-official " side, from the fifteen to one victories of the Hurricanes during the short stay of the wing at Murmansk, to the escort patrols for Russian bombers, during which no bomber was lost, from the rapid formation of the Wing in Yorkshire to the getting acquainted with Russian conditions and Russian personnel.

The author tells his experiences in diary form—vivid and alive and illuminating. To give some extracts, " It may be mentioned in passing that the Hurricanes to be assembled were dumped about, folded up in their crates, in an uneven-lying mud flat; that each 4½-ton crate presented its own problem in the way of getting it into the neighbouring hanger; and that, partly owing to haste in loading the convoy in England, and partly to difficulties in unloading the convoy in Russia, many essential assembling tools—airscrew spanners among them—were missing, and had to be improvised by rule of thumb methods by the Russians before assembly proper could start."

Despite the immense difficulties by working an average of twelve hours a day, fifteen aircraft were unpacked, assembled and flown for a long cross-country trip in nine days, a pretty good record! Here is an extract from Daily Routine Orders: " A reindeer has been taken on Wing strength as from to-day's date. Volunteer (preferably with experience) to report to Orderly Room for duties of grooming, feeding and exercising same." And another, following a wire from England: " The Wing-Commander has authorised the issue to the wing of an extra tot of rum to-night to drink the health of S./Ldr. Miller's newly-born daughter."

This is a most interesting side-show of the R.A.F., and from its description of the operations of the Wings to Russian methods of life and training it is a book well worth reading.

AIRCRAFT NAVIGATION.

Part I, Theory, by H. Stewart and A. Nichols; Part II, Practice, by S. A. Walling and J. C. Hill. (Bound in one volume.) Cambridge University Press. 1943. 5/-.

ELEMENTARY AIR NAVIGATION.

R. K. Vanderford. Gale and Polden, Ltd. 1943. 3/6.

These two books, for the use of Air Cadets and pre-entry R.A.F. trainees, follow the time-honoured syllabus: Form of the Earth, Maps and Charts, Map Reading, Magnetic Compass, Altimeter and Airspeed Indicator, and various dead reckoning problems. Mr. Vanderford's book is the simpler of the two, and beginners would be well advised to read it before the other. Both books are obviously written by competent teachers, are solidly bound and well printed. An unusual feature of " Aircraft Navigation " is that a practice chart and small circular slide rule are supplied in a separate envelope—an arrangement which has the advantage that the chart is larger and of better quality paper than is usual, but the corresponding disadvantage that it is very likely to be mislaid. A pocket on the back cover is a more practicable solution, especially in cases where the book is to be sent out on loan.

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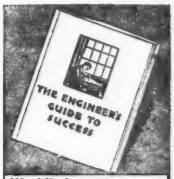

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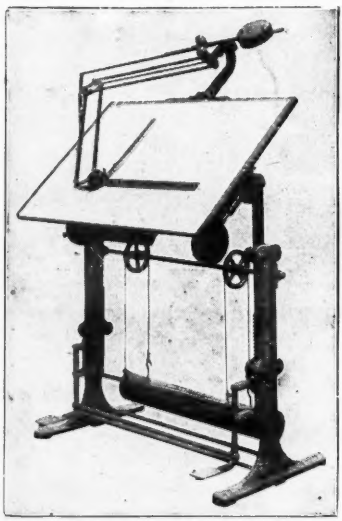

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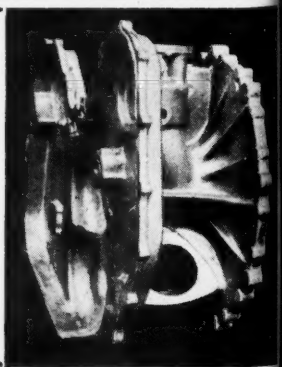

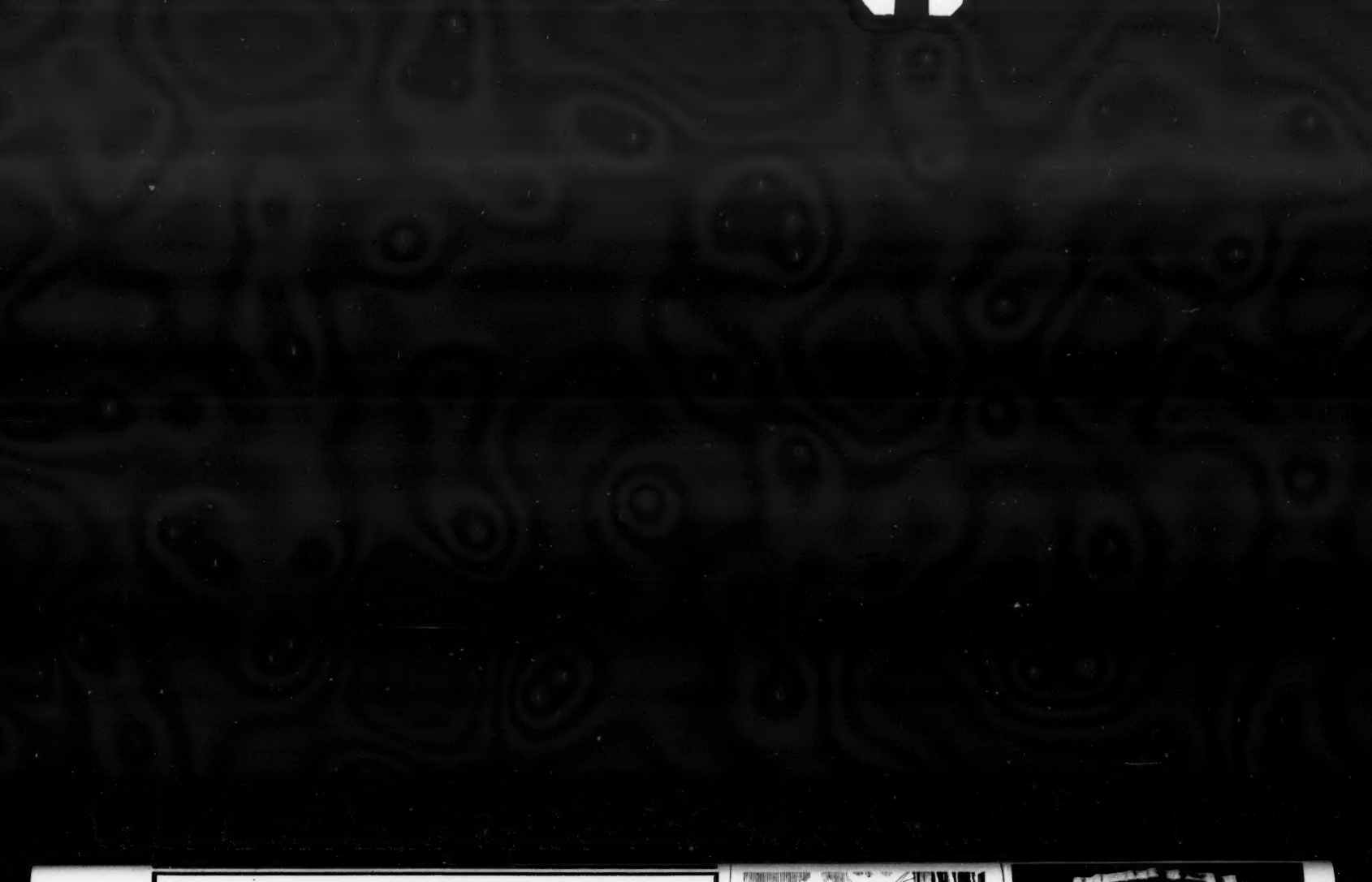

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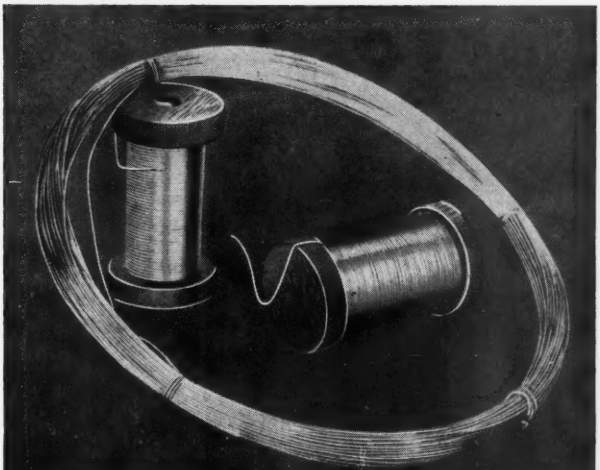

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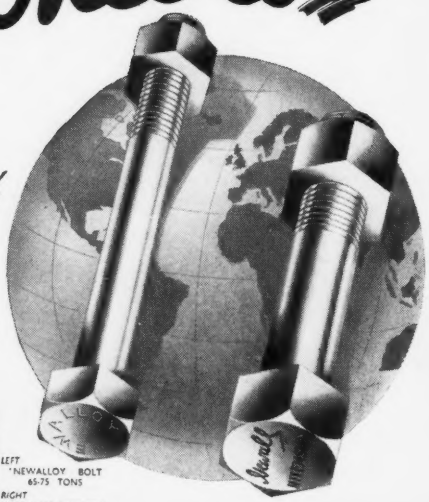

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